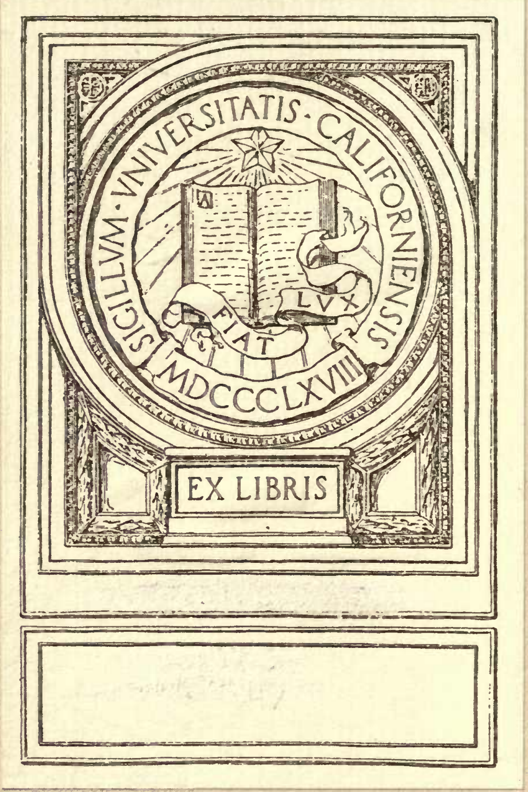
HOUSEHOLD PHYSICS

BRECHNER



A Practical Application of Physics

HOUSEHOLD PHYSICS

BY

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PREFACE

Household Physics was written primarily for girls. The principles of physics in such a book are of course the same as in a text-book for boys or for mixed classes. But in *Household Physics* these principles are *applied* in such a way as to interest girls, by using examples and references with which they are thoroughly familiar.

The work was developed in the classroom. At first the author used an outline, filling in with applications and drawings in the recitation periods. The following year the text was written and mimeograph copies put into the hands of the students. After this material had been carefully worked over with various classes, it was revised into the present book.

The subject of Heat is taken up first, since it is one which has many applications of vital importance to the household. Thus the girl becomes interested in physics from the first, and looks forward to recitations with pleasure.

The language of the book has been kept as simple as possible throughout. The topics are carefully explained and these explanations are illustrated by a wealth of line drawings and photographs. The problems are especially easy and practical.

The author wishes to take this opportunity to thank the several industrial concerns which supplied many of the photographs, and also those teachers and pupils who so kindly assisted him in bringing the work to completion.

C. H. B.

August, 1919.

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HOUSEHOLD PHYSICS

CHAPTER I

HEAT AND HEAT MEASUREMENT

1. Nature of Heat. — *Physics* is a study of the every-day events of life. It is defined as the science of *matter* and *energy*.

Taking the Temperature of Melting Ice to Determine the Melting or Freezing Point.

Matter is anything which occupies space; *e.g.* air, water, wood, iron, etc. Energy is ability to do work.

The student of domestic science must often wonder why some of the remarkable things in cooking, freezing, and melting happen as they do. One of the divisions of physics, the subject of heat, touches closely many of the things done in domestic science work; and it has a vital relation to the coal and gas bills at home.

Heat is one form of energy, and is of two kinds, *molecular heat* and *radiant heat;* sometimes called *sensible heat* and *insensible heat.* Sensible heat can be detected by the senses, while insensible heat cannot.

All substances are composed of molecules, or very small particles of matter, which are never at rest but are always vibrating with great rapidity. In a hot body they vibrate faster than in a cold body. When you heat a flat-iron you make the molecules jump faster. If you rub your hands together, they are warmed by the increased vibration of the molecules.

The energy which molecules possess, due to their vibration, is called *sensible* heat or *molecular* heat. Put your hand on anything hot and you will see how easily sensible heat can be detected by the sense of touch.

Heat comes all the way from the sun to the earth. It travels through air or clear glass without warming it; but when it strikes any object not transparent it is absorbed and warms the object. Heat passing through the air is insensible or radiant heat, but when it strikes a non-transparent object it is changed to sensible or molecular heat.

If you touch a window pane when the sun is shining through, the glass feels cold. If you touch a piece of black cloth lying in sunshine, it feels warm.

Either form of heat may be changed into the other. Sensible heat in the glowing coals of the fireplace starts out as radiant heat, or vibration in ether; but when it strikes you, it is changed back to sensible heat.

2. Hot and Cold. — *Hot* and *cold* are common words used to denote how a body feels to the touch. They are only relative terms, and are not very definite. The term *cold* is negative in meaning, and refers to the absence of heat. Cold does not come *into* your house; but heat goes *out*, leaving it cold, or without heat.

Taking the Temperature of Steam over Boiling Water to Determine the Boiling Point.

3. Temperature. — Since the terms *hot* and *cold* do not give us a definite means of expressing the heat condition of bodies, we use another word, *temperature*. *Temperature is* *the measurement of the speed of vibration of the molecules of an object;* that is, it is a means of expressing the hotness of a body.

4. Thermometers. — Since the sense of feeling is inaccurate, we must have some definite means of measuring temperature; and for such purpose we use the thermometer.

Most substances expand when heated, and contract when heat is removed. This expansion is used to measure temperature. Mercury expands or contracts rapidly and evenly, and therefore is commonly used as the expanding substance in thermometers. Sometimes alcohol containing red dye takes its place. There are several kinds of thermometers, and we must be familiar with two, — Centigrade and Fahrenheit.

The best way to understand these is to learn how they are made, and how the scales are placed on them. First we must have some fixed point, that is, some point which will mean the same temperature everywhere in the world. Pure water furnishes such a point, as it freezes (changes from liquid to solid), or melts (changes from solid to liquid), always at the same temperature, under uniform atmospheric conditions. For another fixed point the boiling temperature of pure water, under uniform atmospheric conditions, is taken.

In making a thermometer, take a glass tube of small uniform bore with a bulb at one end. Fill it partly with mercury, removing all air; then seal it. To put on the Centigrade scale, place the bulb in cracked ice and when the mercury stops falling make a scratch on the glass opposite this point and mark it "0°."

Next place the bulb in the steam just above water boiling under normal pressure. When the mercury stops rising, mark this point "100°." Divide the space between into

100 equal divisions, each one representing one *degree* change of temperature. This is the most convenient thermometer scale we have, since one of the fixed points is at 0°. However, since the Fahrenheit scale is more commonly used in this country, we must learn that also and how to change from one to the other.

On the Fahrenheit scale the freezing temperature of water is marked "32°," and the boiling point "212°." The space between is then divided into 180 equal parts, each called a *degree.*

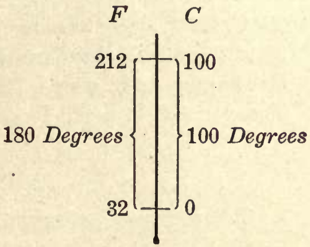

FIGURE 1. — FIXED POINTS ON THE CENTIGRADE AND FAHRENHEIT SCALES.

5. Relation of the Two Scales. — The relation between the two scales is shown in Figure 1. A little study of this figure will show you that an equal space is divided into 100 Centigrade degrees and 180 Fahrenheit degrees. This means that the C. degree is almost twice as large as the F. degree.

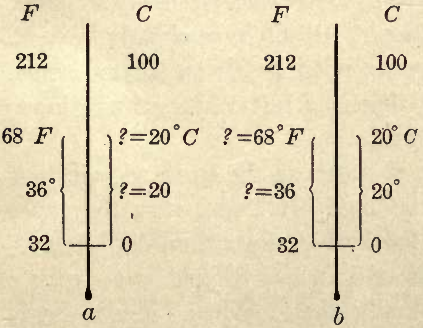

FIGURE 2. — SHOWING HOW TO CHANGE FROM ONE SCALE TO THE OTHER.

That is, 100° C. = 180° F., or
1° C. = $\frac{180}{100}$° F., or $\frac{9}{5}$° F.; and

180° F. = 100° C., or
1° F. = $\frac{100}{180}$° F., or $\frac{5}{9}$° F.

6. Changing from One Scale to the Other. — To change from one scale to the other always make a sketch as shown in Figure 2, and solve as follows:

Problem: Change 68° F. to the corresponding Centigrade reading.
68° F. − 32° F. = 36° F. above the fixed freezing point, (*a*) Figure 2.
$36 \times \frac{5}{9} = 20°$ C. above the freezing point on the Centigrade scale.
Therefore 20° C. is the corresponding Centigrade reading.

Problem: Change 20° C. to F. reading.
20° C. is 20° above freezing point.
$20 \times \frac{9}{5} = 36°$ F. above freezing point on F. scale, (*b*) Figure 2.
But freezing on F. scale is 32° F.
Therefore 32° F. + 36° F. = 68° F., Fahrenheit reading.

Problems

1. Change from Centigrade to Fahrenheit readings: 40° C., − 10° C., − 40° C.

2. Change from Fahrenheit to Centigrade readings: 60° F., 22° F., 40° F.

3. A change of temperature of 28° C. equals what change of temperature on the Fahrenheit scale?

4. A range of 48° F. equals what range on the Centigrade scale?

7. Freezing and Boiling Points. — We have already said that *the freezing point is the temperature at which a liquid changes to a solid.* Such substances as iron, lead, gold, paraffine, and mercury have a freezing or melting point, each differing from the others. As you have already learned, in making ices and ice cream, putting salt on the ice lowers its melting temperature; that is, a salt solution has a lower freezing point than pure water.

When you put a kettle of water on the stove to boil, how do you know when it is boiling? It is not when the vapor begins to come from the kettle, but when it bubbles freely.

If a thermometer is placed in a pan of cold water over a flame, the mercury gradually rises. When bubbles begin to come out of the water, the mercury becomes stationary and will never rise higher, no matter how long or how rapidly you heat the water, if the bubbles are free to escape. If you examine the escaping bubbles at such a time, you will find that they form at the bottom of the vessel, where the heat is applied, rise to the top, and break. They are not bubbles of air, but are bubbles of steam, able to push the air and water back and thus get out of the water. These steam bubbles have the same kind of molecules as liquid water, but the molecules are so far apart that they form a gas instead of a liquid.

The boiling point is that temperature at which the vapor tension is equal to the applied pressure. The *vapor tension* is the pressure exerted by the molecules of the vapor trying to escape. The *applied pressure* is the pressure of the surrounding element.

Freezing and Boiling Points of Some Common Substances

Under Normal Atmospheric Pressure

SUBSTANCE	FREEZING PT.	BOILING PT.
	Centigrade	Centigrade
Oxygen	– 235°	– 182°
Ammonia	– 75°	– 39°
Ether	– 113°	35°
Methylic Alcohol	– 112°	66°
Distilled Water	0°	100°
Acetic Acid	– 17°	117°
Turpentine	– 27°	157°
Fat, Oil, etc.	– 33°	210°
Mercury	– 38.8°	357°

Hardly any two substances have the same freezing or boiling points and some are used for specific purposes because of this. Mercury, for example, is used in the thermometer because its freezing point is low and its boiling point is high. Ammonia is used in the manufacture of artificial ice because its boiling point is low. Doughnuts are dropped into hot fat instead of water because fat boils at about 400° F. and so can be made hotter than water.

8. Effect of Pressure on Freezing and Boiling Points. — When water is placed under a pressure it becomes more difficult to freeze; that is, its freezing point is lowered. Under normal atmospheric pressure water freezes at 0° C. or 32° F., but if it is put under a higher pressure it must be cooled to a temperature lower than 0° C. or 32° F. before it will freeze.

An example of this is to be had in pressing a snow-ball. A good time for snow-balling is when the snow is *damp*, that is, when it is at the freezing point. The loose snow is taken in the hands and pressed. This increased pressure lowers the freezing point below the temperature of the snow, and part of it melts. Then when the pressure is removed the freezing point again goes up to 0° C., and the melted snow freezes again, making the ball hard.

If water were put into a strong vessel and sufficient pressure were applied, the water would stay a liquid, even in our coldest weather.

The effect of pressure on the boiling point is just the opposite of what it is on the freezing point; that is, pressure raises the boiling point. Instead of boiling at 100° C. or 212° F., the water must be made hotter when a pressure above that of the normal atmosphere is put on it. Water in the boiler of a locomotive under a pressure of 200 pounds per square inch boils at 380° F. instead of at 212° F. On the other hand, water under a pressure less than normal atmospheric pressure boils at a lower temperature than 212° F.

9. Application of Effect of Pressure on the Boiling Point. — Water in an open kettle boils at a comparatively low temperature on the top of a high mountain because the pressure of the air is much less than at the sea level. Sometimes this temperature is lower than the cooking temperature of starch; and so at high elevations it is possible to put potatoes into an open kettle and boil the water freely, without cooking the potatoes. In the mountains this difficulty is sometimes overcome by using a pressure kettle (Figure 3), that is, a kettle with a lid screwed on, making it air-tight. This lid holds the steam in the kettle and increases the pressure, thereby raising the boiling point above the cooking temperature.

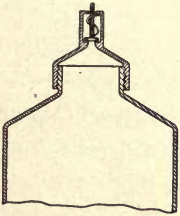

FIGURE 3. — A PRESSURE KETTLE.

Gelatin is a product which comes from the bones of animals. To extract it from the bones a temperature higher than 100° C. is necessary. To get this higher temperature the bones are cooked in a closed vessel, under pressure. (Figure 3.)

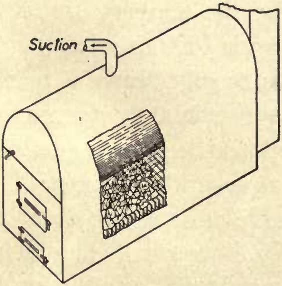

FIGURE 4. — A VACUUM PAN.

In the manufacture of sugar the principal thing is to evaporate the water from the juice of the sugar cane or sugar beet. This is done by boiling, but when the syrup begins to get thick, it is easily burned; so it is put into vacuum pans (Figure 4) which are closed, and part of the air and steam is pumped out, making the pressure inside lower than that of the atmosphere. This causes the syrup to boil at a lower temperature, and so prevents scorching of the sugar.

10. Quantity of Heat. — *Temperature* and *quantity of heat* mean very different things. The water in a tea-kettle may be at the same temperature as the water in a lake; yet the lake would have much more heat. Even if the water in the tea-kettle were boiling, the lake would have more heat, though the water in it might be ice-cold.

The term *quantity of heat* does not refer to the temperature of the body, but denotes the amount of energy in the vibration of its molecules.

11. Heat Units. — The quantity of heat can be measured, but not by our familiar units of *pound, gallon, foot,* etc. Other kinds of units must be used, and these are based on the effect produced upon water when heat is applied. They are *B. T. U.* (*British Thermal Unit*), *calory*, and *great calory*.

The *B. T. U.* is the amount of heat required to raise the temperature of 1 pound of water 1° F. The *calory* is the amount of heat required to raise the temperature of 1 gram of water 1° C. The *great calory* is 1000 calories.

In these definitions we see that no certain degree is mentioned. This is because it takes approximately the same amount of heat to raise the temperature of a certain amount of water any one degree as to raise it any other degree.

Although the calory and B. T. U. are units of two distinct systems, there is a definite relation between them. For all practical purposes, 1 B. T. U. equals 250 calories, or 1 great calory equals 4 B. T. U.'s.

12. Heat of Fusion. — If a piece of ice is placed in a pan on the stove, the ice begins to melt; but the temperature of the water does not rise. Both the ice and the water stay at 0° C. or 32° F. until all the ice is melted. After that, the water begins to get warmer. The question is: Where did all the heat go while the ice was melting? It was used to melt the ice.

As we have learned, everything that occupies space is made up of small particles, called molecules. When the water is frozen solid, these molecules are drawn together by a force called *cohesion;* and this force keeps them in place. When the ice melts, the molecules are torn apart, and slip past one another, making it possible to *pour* the water. To tear these molecules apart requires energy; and this energy is the heat which melts the ice.

In other words, we can say: While the ice is melting, the heat supplied is used to tear the molecules apart, changing the solid to a liquid.

Some substances require more energy to tear the molecules apart than others; so in order to melt some substances more heat is required than to melt others. *The heat required to change a unit mass of a substance from a solid to a liquid is called the* **heat of fusion** *of that substance.*

If a pound of ice at 32° F. were put on the stove and heated, it would have to take up 144 B. T. U.'s before it would be all melted. If a *gram* of ice were used instead of a *pound,* 80 calories would be required to melt it.

The heat of fusion of ice is the amount of heat required to melt 1 pound of ice without changing its temperature. This has been found to be 144 B. T. U.'s. (English system.)

Or, *the heat of fusion of ice is the amount of heat required to melt 1 gram of ice without changing its temperature. This has been found to be 80 calories.* (Metric system.)

On the other hand, when water freezes, it gives out as much heat as it takes in when the same weight of ice melts; that is, when 1 pound of water freezes, it gives off 144 B. T. U.'s; and when 1 gram of water freezes, it gives off 80 calories.

13. The Refrigerator. — Every one is familiar with the refrigerator. It is a box with special walls so constructed that heat cannot easily get through them. A compartment is made to put ice in, and at least one other compartment is made to hold the butter, meat, fruit or any article one wishes to keep cold. Later a more thorough study will be made of the construction of the refrigerator. All we are interested in now is that it is a box in which to place ice to keep articles cool so they will remain fresh.

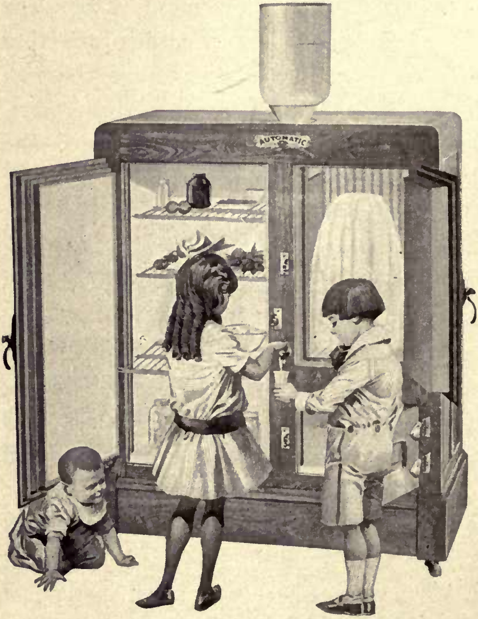

Figure 5. — A Refrigerator.

The ice, when placed in the refrigerator, begins to melt; but, to melt, it must have heat. It takes the heat from the other things in the refrigerator; and thus keeps them cool. For every pound of ice that melts, 144 B. T. U.'s must be used up.

Two refrigerators can be tested as follows: Place equal weights of ice in the two empty refrigerators. Close the doors, and note the time required for the ice to melt in each. The one in which the ice melts first lets in the more heat, and hence is not so good as the one in which the ice lasts longer.

14. Freezing Ice Cream. — The freezer in which ice cream and ices are frozen is made up of two compartments; one, a can, which fits very loosely into the other, a wooden pail. (Figure 6.)

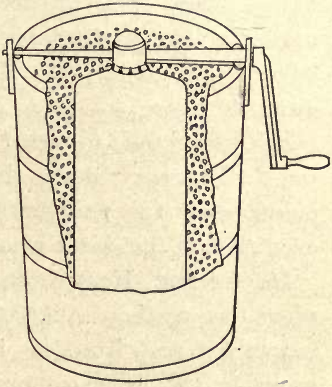

FIGURE 6. — LINE DRAWING OF AN ICE CREAM FREEZER.

The cream, with its other ingredients, is placed in the inner can, which, in turn, is placed in the wooden pail. Cracked ice, mixed with salt, is packed firmly around the can. Then the can is kept turning, so that the cream will not freeze in lumps. But what makes the cream freeze at all? When the ice begins to melt it takes the heat from the cream, thus reducing its temperature.

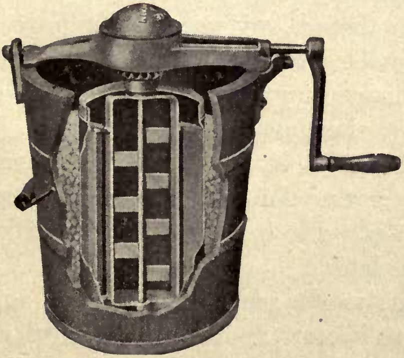

FIGURE 7. — PHOTOGRAPH OF AN ICE CREAM FREEZER.

But the cream would never freeze if salt had not been put on the ice.

When pure ice melts, its temperature is 0° C. or 32° F., a temperature at which cream will not freeze. But when salt is mixed with the ice, the freezing point is lowered until the temperature has been reduced several degrees below 0° C. or 32° F. This low temperature causes the cream to freeze.

Salt is also used to melt the ice on a sidewalk in the winter time. The salt reduces the freezing point of the ice to a point below the temperature of the air, and so it melts, even though the water is still freezing in the gutter.

15. Getting Heat from Freezing Water. — Sometimes when the weather is likely to be cold enough to freeze the vegetables and fruits in the cellar, farmers put tubs of water in the cellar to protect them. If water is in the cellar, it will begin to freeze just as soon as the temperature gets as low as 0° C. or 32° F. The vegetables and fruits will not freeze at this temperature, because they contain solutions of sugar. As the heat leaks out of the cellar, more water freezes, giving up its 144 B. T. U.'s per pound, and keeping the temperature up to 0° C. or 32° F.

This goes on as long as there is any water left unfrozen; and so protects the vegetables and fruits. Should all the water freeze, then the temperature may fall low enough for these things to freeze also; therefore, large tubs are used.

16. Effect of Heat of Fusion on Climate. — In regions near large bodies of water the climate is affected by the high heat of fusion of water. The general effect is to make both fall and spring come later.

At the end of summer, as the weather gets colder and colder, the water begins to freeze. As it freezes, it gives off 144 B. T. U.'s per pound, and thus keeps the temperature up to 0° C. or 32° F.; just as putting water in the cellar to keep the vegetables from freezing kept the temperature of the cellar up to 0° C. or 32° F. This, then, causes the fall to be late.

Again, at the end of winter, when the weather gets warmer, the ice begins to melt. In melting, it takes in 144 B. T. U.'s for every pound; and so keeps the temperature down to 0° C. or 32° F.; just as putting ice in the refrigerator keeps the things in it cold. Thus, the spring is also late.

This fact has much to do with fruit-raising. More fruit is destroyed by changeable weather in the spring than by anything else. If a few warm days come the last of March or the first of April, the buds on the fruit trees start. Then, if a cold snap comes, the buds are frozen, and the fruit is ruined. Near a large body of water the melting ice may prevent a warm period early in the season, so that the buds do not start until there is no danger of frosts.

Problems

1. How many B. T. U.'s are required to melt 50 lb. of ice in a refrigerator? Where does the heat come from?

2. When a tub of water, weighing 60 lb., is placed in the cellar, and it all freezes, how much heat is given up? Where does the heat go?

3. How many calories are required to melt 25 grams of ice at 0° C. and raise its temperature to boiling?

4. If 100 grams of ice at 0° C. are placed in 400 grams of water at 30° C., and if, after all the ice is melted, the temperature is 8° C., how much heat was given up by each gram of ice *in melting?*

17. Heat of Vaporization. — If a pan of water is placed on the stove and heated, its temperature gradually rises until the water begins to boil. After that, the temperature remains constant until all the water is boiled away, just as in the preceding experiment the temperature remained constant until all the ice was melted. While the water is boiling, the heat supplied goes to change the liquid to a gas.

We have seen that it takes heat to change ice to a liquid and that the heat is used to tear the molecules apart. The same thing happens when a liquid is changed to a gas. In the form of a liquid, water still has the force of *cohesion*, the force of holding its molecules together, so that the water stays in a body and remains in the bottom of a vessel.

When the liquid changes to a gas or vapor, the molecules, being much farther apart, do not attract one another perceptibly, but fly as far apart as the containing vessel allows them to go. The energy needed to tear them apart is the heat we supply in boiling the water.

The amount of heat necessary to change a unit weight of a liquid to a gas without changing its temperature is called its **heat of vaporization.**

The heat of vaporization of water is the amount of heat necessary to change 1 pound of water to steam without changing its temperature. This has been found to be 966 B. T. U.'s per pound. (English system.)

Or, *the heat of vaporization of water is the amount of heat necessary to change 1 gram of water to steam without changing its temperature. This has been found to be 537 calories per gram.* (Metric system.)

When water vapor or steam condenses, it gives up the same amount of heat as was taken in to vaporize it, that is, 537 calories per gram, or 966 B. T. U.'s per pound.

The heat of vaporization has many applications in steam heating of houses, effect on climate near a large body of water, steam cookers, double boilers, etc.

18. Steam Heating of Houses. — Due to the great heat of vaporization of water, steam is very commonly used for heating buildings. The steam is sent through radiators in the rooms, and the 966 B. T. U.'s per pound, absorbed when the water was changed to steam, is given to the air of the room when the steam condenses in the radiators.

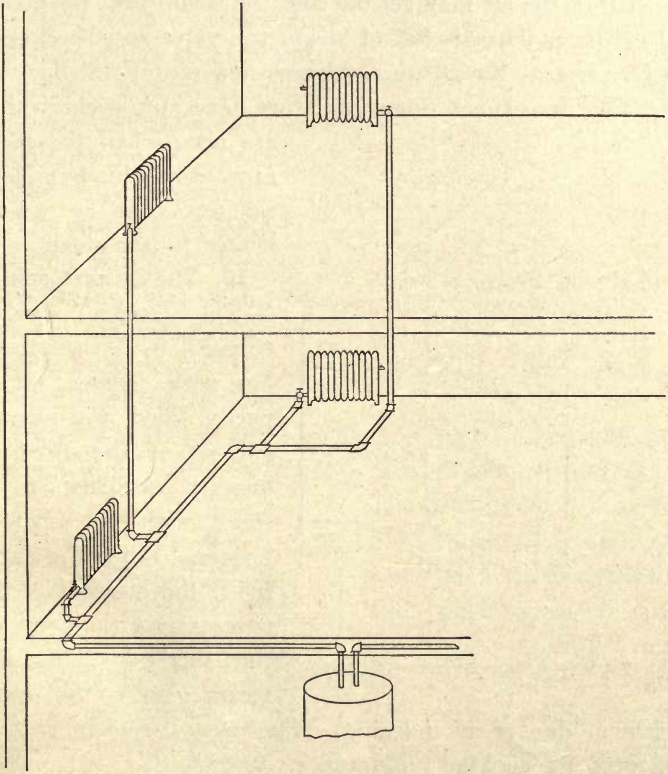

FIGURE 8.—A STEAM-HEATING SYSTEM.

There are several systems of steam-heating. Figure 8 shows one of them. This is called the one-pipe system. The steam is led out of the top of the boiler in the basement to the radiators in the different rooms. Here it condenses, gives off its heat, and the condensed water runs back down the same pipe.

To get the steam into the radiator at the start, the little stop-cock at the top of the radiator should be opened in order that the air may get out and the steam take its place. After the radiator is full of steam the valve can be closed, and as fast as the steam condenses new steam will flow up and take its place. Some radiators have stop-cocks which are open when the radiators are cold, but close automatically when heated by the steam.

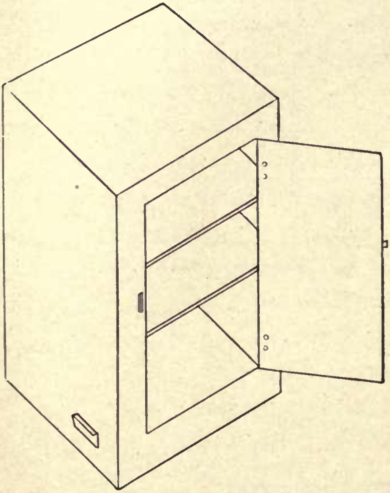

Figure 9. — A Simple Steam Cooker.

19. The Steam Cooker. — The steam cooker (Figure 9) is a closed box with shelves. It is partly filled with water and set on the stove, or directly attached to a stove with a separate burner. When the water boils, the steam fills the space about the food on the shelves. This hot steam cooks the food, without danger of burning. The steam cooker is well adapted for cooking puddings, custards, etc.

20. The Double Boiler. — The double boiler is a combination of two vessels. (Figure 10.)

The smaller, containing the food to be cooked, is set inside a larger vessel, partly filled with water. The food can be cooked for a long time and cannot burn as long as there is water in the outer vessel. The temperature never rises above 100° C. or 212° F.

21. Distillation.—The question of pure drinking water is of vital importance, especially in large cities. Sometimes chlorine is put into the water to kill the germs. As chlorine is very distasteful to some people, they prefer to buy, or prepare, distilled water.

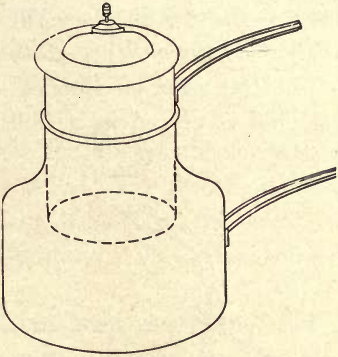

FIGURE 10. — LINE DRAWING OF A DOUBLE BOILER.

The process consists of boiling the water, converting it into steam, and then condensing this steam, thus procuring pure water. Figure 12 shows the principle used even in large establishments.

Water is heated in a boiler (*B*), and the steam is conducted through a pipe to a coil (*C*), in a tank of running cold water. The cold water is supplied by a hose from the city water main to the point *a*, and when warmed flows out of the opening *b* into the sewer or into a tank. The steam, passing through the coil, is condensed, giving up its 966 B. T. U.'s per pound to the cold water, and then runs out of the coil as pure water. It is pure because only the water will evaporate; hence only pure water vapor is in the coil to condense.

FIGURE 11. — PHOTOGRAPH OF AN ALUMINUM DOUBLE BOILER.

Distillation is used to refine other substances, such as alcohol and turpentine. But in these cases the substance has to be distilled several times, and the process is then called *fractional distillation.*

In the case of alcohol, the liquid which contains the alcohol is placed in a boiler and heated, the temperature being kept at the boiling point of alcohol, which is below the boiling point of water. The alcohol vapor is driven off, but with it a little water evaporates. When this is condensed again, it still contains some water. This new liquid is again distilled, yielding a product more nearly pure alcohol. This process is kept up until the liquid is as nearly pure as desired.

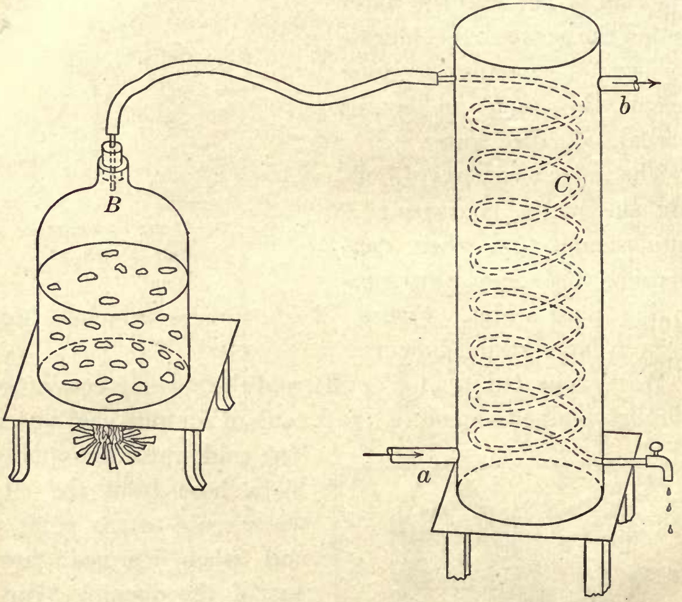

FIGURE 12. — DIAGRAM OF A SIMPLE DISTILLATION SYSTEM.

22. Other Applications of Heat of Vaporization. — In the summer time, regions far inland get very warm. But near a large body of water the heat is less intense because, in evaporating, the water takes up 966 B. T. U.'s for every pound evaporated; and thus keeps the temperature lower than it would otherwise be.

You have probably noticed that the air gets cooler after you have sprinkled the street or lawn. The water on the ground begins to evaporate, taking heat from the ground and air, thus lowering the temperature. The same thing occurs after a rain.

Nature uses the same principle to keep your body cool. When you exert yourself strenuously, or when the day is warm, perspiration is thrown out to the surface by the skin. This perspiration evaporates, taking the heat from the body to do it. Would you get as cool if you removed the drops with your handkerchief?

23. Artificial Ice Plant. — In making artificial ice, the same principles apply as in natural evaporation and freezing. The ice freezes as naturally as the ice on a lake. The only artificial part is the producing of the low temperature. Nature does the rest.

The artificial ice plant (Figure 13) consists of four principal parts: a cooling coil (A) for the ammonia gas; a force pump (P) for compressing the ammonia gas; an expansion coil (B) where the brine cools; and a freezing tank (C) where the ice is frozen.

The operation of the plant is as follows: the force pump P draws the ammonia gas through the valve d and forces it through the valve e, under high pressure. From here it is led through the coils in the tank (A), where it is cooled by running cold water.

As the gas, under high pressure, becomes cool, it condenses and is led out of the coil at the bottom as liquid ammonia. At the stop-cock *f* the liquid is allowed to flow through slowly, and there it turns to a gas and expands suddenly. This evaporation and expansion require a great amount of heat.

As this evaporation and expansion take place in the coil in the tank (*B*), the heat is taken from the brine in tank (*B*), thus reducing its temperature several degrees below 0° C. or 32° F. The ammonia gas then passes on up to the force pump, to be again compressed and used over. The cold brine is pumped from tank (*B*) to tank (*C*). In (*C*) are placed the molds containing pure water. The heat passes from the water to the brine, and thus the water freezes.

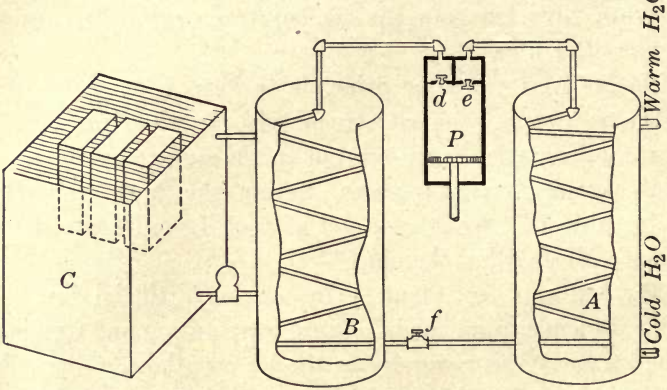

FIGURE 13. — DIAGRAM OF A SIMPLE ARTIFICIAL ICE PLANT.

In iceless refrigerators cold brine is pumped through coils just as in the artificial ice plant. Modern meat markets use this method.

The ice in artificial ice skating rinks is frozen by the method above. Coils of pipe are placed on the bottom of the floor, and then enough water is run over it to cover these pipes an inch or two. Brine is pumped through the pipes, which in turn freezes the water. In this way ice skating can be had at any time of the year.

Problems

1. Find the heat required to evaporate two pounds of water without changing its temperature.

2. Find the heat required to evaporate 1500 grams of water without changing its temperature.

3. If, in making jelly, one half of the weight of the juice is boiled away, how much heat is required to make one quart of jelly? (Take weight of juice as eight pounds per gallon, and starting temperature as 62° F.)

4. When ten pounds of steam is condensed in your radiator, how much heat is given to the room?

24. Water Vapor in the Air. — When water is boiled away in a tea-kettle or a pan, or when it evaporates from any body of water, the water seems to disappear; but it does not go out of existence. It simply goes into the air and is invisible. The molecules of water vapor mix with the molecules of other substances in the air, of which they become a part.

There is a limit to the amount of water vapor that the air will hold, and this limit depends upon the temperature of the air. The warmer the air, the more vapor it will hold.

When the air contains all the water vapor it will hold, it is said to be *saturated,* or to have reached the *saturation point.* The saturation point depends upon the temperature.

The following table shows the vapor tension of water under normal pressure at different temperatures.

TEMPERATURE	VAPOR TENSION (cm. of mercury)	TEMPERATURE	VAPOR TENSION (cm. of mercury)
0° C.	0.460	21° C.	1.862
16° C.	1.362	22° C.	1.979
17° C.	1.440	23° C.	2.102
18° C.	1.546	24° C.	2.232
19° C.	1.645	25° C.	2.369
20° C.	1.751	100° C.	76.000

25. The Hygrometer. — An instrument used to measure the amount of water vapor in the air is called a *hygrometer*. Figure 14 shows a common form of the hygrometer. It consists of a small spring, a pointer, and a scale. The scale denotes the per cent of water vapor in the air, complete saturation being 100 per cent. For example, a reading of 65 per cent means that there is 65 per cent as much water vapor in the air as it would hold if saturated.

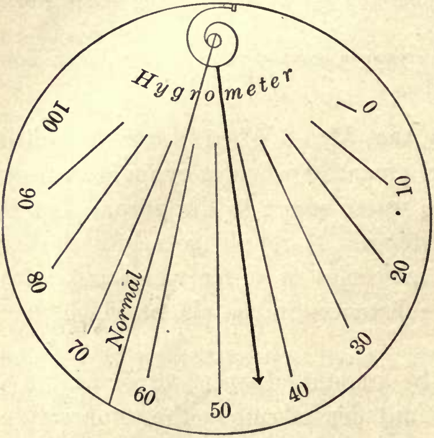

FIGURE 14. — THE HYGROMETER.

By knowing the weight of vapor required at a certain temperature to saturate the air, with the hygrometer reading it is easy to compute the exact weight of vapor that is in the air.

If saturated air is heated to a higher temperature, it will hold more vapor; but if saturated air is cooled it will hold less, and some of the vapor must condense.

26. Dew. — If warm air comes in contact with a cold object it may be cooled below the saturation point and some of its water vapor may condense and appear as drops on the cold object. These drops are called *dew*. You have all seen a pitcher of ice water *sweat* in the summer time. The pitcher does not really sweat, but merely has dew on it.

Dew also forms on grass and on the leaves of trees. During the night small objects, such as the grass blades and leaves, *radiate* their heat; and thus become cooler than the surrounding objects. These grass blades and leaves then cool the air that touches them, and dew forms when the air is moist.

27. Fog and Clouds. — If a cool current of air strikes a warm current, the warm air is cooled below the saturation point, and the surplus water vapor condenses in very small particles, but large enough to be visible. If this condensation occurs near the surface of the earth, it is called *fog*. If it occurs high in the air, it is called *clouds*. The greatest fog region in the world is just off the banks of Newfoundland, where the cold air from the north meets the warm air from the Gulf Stream.

28. Mist and Rain. — If, in the case of *fog*, the condensed particles become sufficiently large to fall slowly, they are called *mist*. If these particles become large enough to fall rapidly, they become drops and are called *rain*.

29. Snow and Hail. — When the water vapor is forced to condense at a temperature below the freezing point, the small particles freeze as they condense and form snowflakes. The flakes get larger and larger as they come into contact with one another in the air.

The formation of hail is more complex than that of the other forms of condensed water vapor we have noted. Scientists are not entirely agreed as to the facts concerning the process. The theory generally accepted is that a small particle of water is condensed and frozen high up in the air. It starts to fall and collects on its surface a layer of water; but before it hits the earth it is carried up again by an upward current of air. This water freezes on its surface, while at the high altitude, forming a new layer of ice. Again it starts to fall, and collects a new layer of water, only to be carried up again by another upward current. This process is repeated until the hail stone becomes so heavy that it cannot be carried up any more.

This theory of formation is based upon the structure of a hailstone. When cut open, it is found to be made up of distinct layers; some of clear ice and some of snow ice.

30. Heat Capacity. — If you heat a five-pound flat-iron to the boiling point, and place it in a pan of cold water, and if you then pour five pounds of boiling water into another pan containing an equal amount of equally cold water, you will find that the five pounds of boiling water have made the pan into which it was poured much warmer than the flat-iron has made the pan in which it was placed.

What conclusion would you draw from this? Note that the weights of the boiling water and the hot iron were the same; that they were at the same temperature; and that they were put into the same weights of water, which were also at the same temperature. The answer is, the water contained more heat than the iron. Different substances hold different amounts of heat at the same temperature. In other words, they have different *capacities* for heat.

The definitions of our heat units are based on the heat capacity of water. We say that when *1 gram* of water is heated *1° C.*, a *calory* is put into it; and that, if *1 pound* of water is heated *1° F.*, a *B. T. U.* is put into it.

But if a gram of any substance other than water were to be heated *1° C.*, it would not take exactly *1 calory*, but a certain *fraction of a calory*, depending upon the substance.

The **heat capacity of a substance** *is the heat required to raise a unit weight of the substance 1°.* If it is in the English system, *it is the number of B. T. U.'s required to raise 1 pound of the substance 1° F.;* if it is in the metric system, *it is the number of calories required to raise 1 gram of the substance 1° C.*

31. Specific Heat. — As the heat capacity of pure water is uniform, substances having different heat capacities are compared with water as a standard. From this comparison we get the term *specific heat.* **The specific heat of a substance** *is the ratio of the heat capacity of the substance to the heat capacity of pure water.*

Eliminating the idea of *heat capacity,* we can define specific heat in this way: *Specific heat is the ratio between the amount of heat necessary to raise a certain weight of the substance 1° and the amount of heat necessary to raise the same weight of pure water 1°; or*

$$\text{Specific Heat} = \frac{\text{Heat to raise substance } 1^\circ}{\text{Heat to raise equal weight of water } 1^\circ}$$

Table of Specific Heats of Some of Our Most Common Substances

SUBSTANCE	SPECIFIC HEAT
Aluminum	.22
Brass	.094
Copper	.095
Iron	.1138
Mercury	.038
Lead	.031
Ice	.5
Air (at constant pressure)	.2375
Hydrogen (at constant pressure)	3.4
Steam (at constant pressure)	.48

FIGURE 15.—A HOT WATER BOTTLE.

32. Application of Specific Heat. — The high specific heat of water has a powerful effect on the climate of regions near a large body of water. This effect is the same as that produced by the high **heat of fusion.** The principle is slightly different, for the heat is used to raise the temperature of the water, instead of to melt the ice. (See § 16.) The effect is much greater than it would be if the body were mercury or alcohol or any substance whose specific heat is less than that of water. The hot water bottle is an application of specific heat. It is better than a hot flat-iron or other hot object, not only because it is more convenient, but also because it holds more heat.

CHAPTER II

EXPANSION

33. Expansion. — One effect of heat is to make the molecules of a body vibrate faster. This increase in speed causes the molecules to take up more space. The molecules themselves do not get any larger, but they require more free space in which to vibrate.

Suppose a number of people were to stand close together, with a large rubber band stretched around the whole crowd. If all stood perfectly still, they could get into a comparatively small space. But if every one began swaying and elbowing his neighbor, each person would take up more room, and consequently the space occupied would be larger, and the rubber band would have to stretch.

This is what takes place when a body is heated; and we call it *expansion. Expansion is the increase in length or volume of a body.*

34. Coefficient of Linear Expansion. — All substances do not expand at the same rate. For example, a bar of iron a foot long would not expand as much as a bar of brass a foot long, if both were heated through the same range of temperature. In order to have a way of expressing how much a substance expands we use the term *coefficient of linear expansion.*

The coefficient of linear expansion of a substance is its expansion per unit length per degree C.

Suppose a bar of aluminum, 60 cm. long at 25° C. (Figure 16), gets .1 cm. longer when heated to 100° C. The increase in temperature from 25° C. to 100° C. is 75° C. If the bar expands .1 cm. for 75° C., it will expand $\frac{.1}{75}$ cm. for 1° C. If 60 cm. expand $\frac{.1}{75}$ cm., then 1 cm. will expand $\frac{.1}{75 \times 60}$ cm. or $\frac{.1}{4500}$ cm. = .000022^{+} cm.

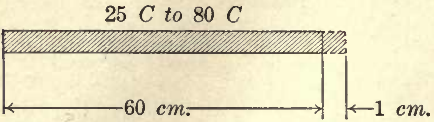

Figure 16. — Expansion of a Rod.

The number .000022 is called the *coefficient of linear expansion* of aluminum.

Table of Coefficients of Linear Expansion

Substances	Coefficient	
Aluminum	.0000222	
Brass	.0000187	
Copper	.000017	
Glass	.0000083	
Iron	.0000112	
Platinum	.0000088	
Steel	.000013	(tempered)
Steel	.000011	(untempered)

If the range in temperature is given in F. degrees, then the above coefficients must be multiplied by $\frac{5}{9}$.

35. The Thermostat. — The thermostat which regulates the heat of our rooms uses the principle of expansion. It is constructed as shown in Figure 17. The pointer (P) is made of a strip of steel (S) and a strip of brass (B), laid side by side and fastened so that they cannot slip on each other. One end is fixed, and the other end is free. Electric connections are made as shown in the figure. The battery (*Bat.*) is placed in the circuit, together with two magnets (M_1 and M_2).

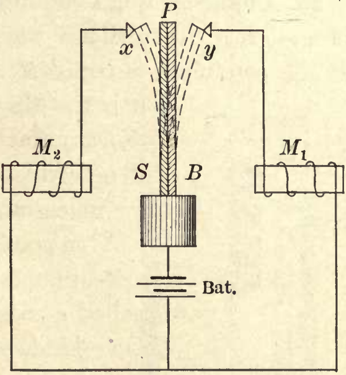

FIGURE 17. — DIAGRAM OF A THERMOSTAT AND SYSTEM.

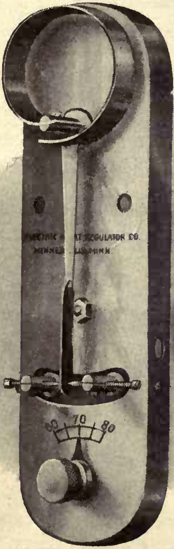

FIGURE 18. — PHOTOGRAPH OF THE SENSITIVE PART OF A THERMOSTAT.

The thermostat is placed in the room, the temperature of which is to be regulated, and the magnets (M_1 and M_2) are placed in the basement. The wires lead from the thermostat to the magnets. When the room gets too warm, the two metals expand; but the brass expands the faster. This makes the pointer bend and touch the connection x, thus operating magnet M_2. Magnet M_2 releases a spring which closes the draft of the furnace, and this allows the room to cool. When it gets cool enough, the two metals contract; but the brass one contracts the more. This makes the pointer bend in the other direction, and it touches the contact point y. This operates magnet M_1, which releases a spring opening the draft. In this way a room may be automatically kept at an even temperature.

36. Compensating Pendulum of a Clock. — The pendulum of a clock is the regulator which makes the clock run evenly. If the pendulum is too short, the clock runs too fast; and if it is too long, it runs too slowly.

Since metals expand when heated, a clock will not run correctly at different temperatures unless a special pendulum is arranged. When a pendulum is so arranged that a change in temperature does not affect it, it is called a *compensating* pendulum.

One kind of compensating pendulum is shown in Figure 20. The dark lines represent rods which are made of brass, while the other ones represent rods of steel. By looking at the figure you will see that the steel rods make the pendulum longer when they expand, and the brass rods make it shorter when they expand. The lengths of brass and steel are so calculated that whenever the steel rods let the bob down the brass rods lift it up the same amount. This

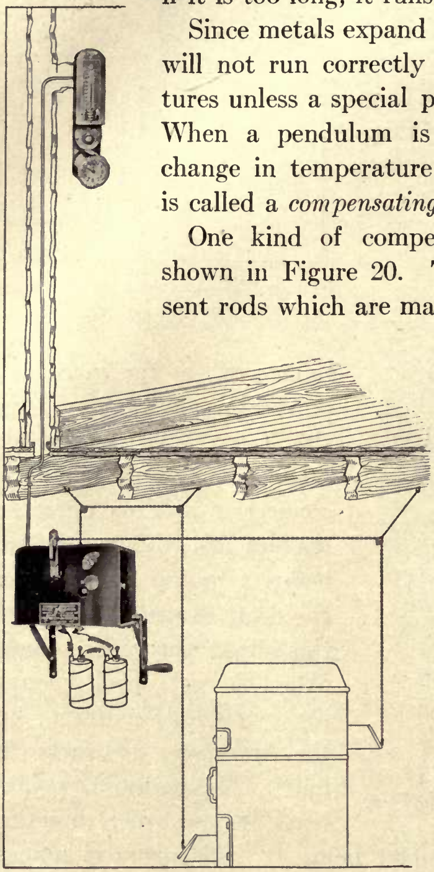

Figure 19. — A Thermostat Installed.

keeps the pendulum at the same length, regardless of the temperature. Another method of accomplishing the same thing is shown in Figure 21.

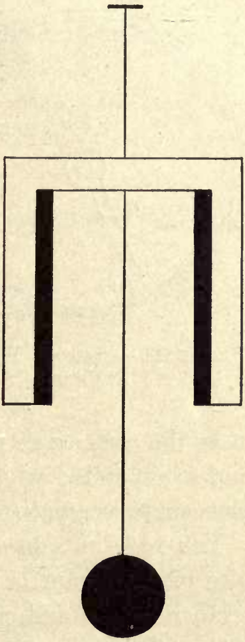

FIGURE 20. — A COMPENSATING PENDULUM WITH BRASS AND STEEL RODS.

The pendulum has a cup at the bottom, containing mercury. As the temperature rises, the rod of the pendulum becomes longer; but at the same time the mercury expands and rises in the cup, thus counteracting the expansion of the rod.

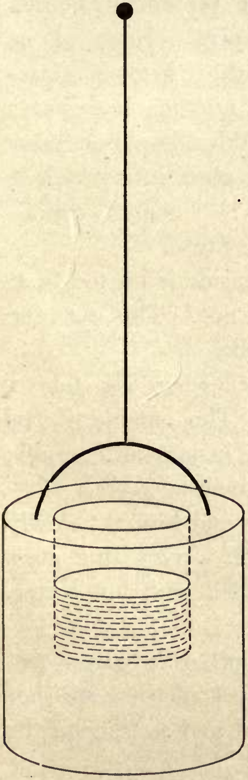

FIGURE 21. — A COMPENSATING PENDULUM WITH A MERCURY WELL.

37. Balance Wheel of a Watch. — Good watches have to be so made that change of temperature will not affect them. The balance wheel is to the watch what the pendulum is to a clock. If the wheel gets larger, the watch runs more slowly; and vice versa. The rim of the wheel (Figure 22) is made of two metals, steel and brass, just as is the pointer of the thermostat. The brass is put on the outside of the rim; so that, when the temperature rises and the spoke gets longer, the brass expands faster than the steel and makes the rim curve more, tending to make the wheel smaller. These two effects exactly counterbalance each other, and so the watch keeps even time.

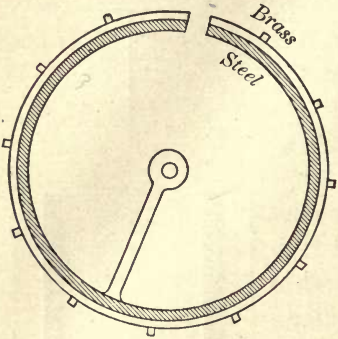

FIGURE 22. — BALANCE WHEEL OF A WATCH.

38. Hot Water Dangerous to Glassware. — Each of us has probably broken glassware by putting hot water into it. Why does hot water break the glass into which it is poured? Unequal expansion is the cause.

As the water goes into the glass the inside is heated first, and so expands; while the outside does not. This puts the glass under a great stress, and so it breaks.

You feel the same effect in your teeth when you take a bite of ice cream or drink ice water. The outside of the teeth is cooled and contracts before the inside can cool off; and so the nerves are squeezed under a high pressure.

If glasses are put into a pan of water and brought slowly to a boil, they will not break; nor will a very thin glass break as easily as a thick one when filled with hot water. Explain.

When glass stoppers stick, they can often be gotten out of bottles by applying a flame to the neck of the bottle for a short time. This causes it to expand and so loosens the stopper.

Thrusting the neck of the bottle into warm water will produce the same result.

39. Coefficient of Cubical Expansion. — When a body is heated, it gets larger in every direction. Therefore it has more volume. This increasing in volume is called *volume expansion*. **The coefficient of volume expansion** *is the increase in volume per degree C., per unit volume.*

Since a body expands in three directions, its coefficient of volume expansion is *approximately* three times its coefficient of linear expansion.

For example: What is the increase in volume of 1000 cubic centimeters of aluminum for a range of 50° C.?

The coefficient of linear expansion for aluminum is .000022; so the coefficient of volume expansion is $.000022 \times 3 = .000066$.

Then $1000 \times .000066 \times 50 = 3.3$ c.c.

Therefore the 1000 c.c. of aluminum will increase 3.3 c.c.;
or will then contain $1000 + 3.3 = 1003.3$ c.c.

Problems

1. Find the increase in length of an aluminum bar 60 cm. long when it is heated from 22° C. to 100° C.

2. If an iron steam pipe leading from the boiler in the basement to an upper story room is 120 ft. long, and 20° C., how much will it expand when steam at 100° C. is passed through it?

3. Will the lids fit tighter when the stove is hot or when it is cold? Why?

4. If the pointer of a thermostat is 2″ long, and is made of brass and steel, what is the difference in length of the brass and steel when it is heated 10° C.?

5. How much will a copper wire 10 ft. long expand in length if heated from 60° F. to 180° F.?

6. How much will 6000 c.c. of brass expand when heated from 32° F. to 212° F.?

7. Will a glass flask hold more when hot or cold? Why?

40. Peculiar Expansion Effects when Water is Heated. — Nearly all of our common substances expand when heat is applied, regardless of their state and temperature. For example a piece of iron will expand when heated; and when it melts, it still expands; and when the molten metal is heated, it still expands; and likewise when it is vaporized and the gas is heated. Expansion takes place whenever heat is applied.

But there is an exception to this rule. The exception is when ice is melting, and when the water is heated from 0° C. to 4° C.

If a piece of ice at a temperature below 0° C., say −10° C., is heated, its temperature rises to 0° C., and the ice *increases* in volume. Then, if more heat is applied, the ice melts, the temperature remaining at 0° C.; but the volume *decreases*. After it is all melted, the temperature again rises; and until 4° C. is reached, the water still contracts. After 4° C. is reached, the temperature continues to rise to 100° C., but the water *expands*. At 100° C. the water changes to steam, the temperature remaining at 100° C. until it is all steam; and the volume *increases* to about 1650 times its former volume. If, after the water is all steam, it is still heated at constant pressure, the temperature increases, and the gas expands.

The best way to remember all this is to keep in mind that water is like all other common substances and expands when heated, *except* when melting and being raised from 0° C. to 4° C.

41. Importance of 4° C., the Temperature at which Water is Densest. — Did you ever think why the rivers and lakes freeze on top instead of at the bottom? The reason is that water is densest, — or, in other words, heaviest, per cubic unit, — at 4° C.

In the summer time the temperature of the water may reach 18° C. or 20° C. As the weather gets cooler in the fall, the top layers of water are cooled by the air. They are then heavier than the layers below them; so they sink until they come to water as cool as, or cooler than, they are. This leaves exposed to the air a new layer which in turn cools and sinks.

This displacement is kept up until the whole body of water is cooled to 4° C. Then, when the top layer gets colder than 4° C. it expands, and becomes lighter than the water below it; therefore, it remains on top, continuing to get colder and lighter. When it reaches 0° C., it freezes and expands still more. This ice layer protects the unfrozen water, which remains at 4° C., except for the layers next the ice.

If water were like mercury and continued to contract as it cooled, large bodies of water would freeze solid in cold weather. The water would cool at the top and sink, letting the warmer water come to the surface. This would continue till all the water was at the freezing point, when the top would begin to freeze. Then the ice would sink; and the lakes and rivers would be frozen from the bottom up. In a cold winter they would be a mass of solid ice.

Then in the summer the ice would melt only on top, leaving the lake almost a solid cake of ice. The result would be a climate too cold for vegetable life.

42. Why Water Pipes Burst. — When water is allowed to remain in the water pipes in very cold weather, it freezes and expands, thus breaking the pipes. The ice acts as a plug in the pipe, otherwise the expansion would force the water back into the water mains, in which case the pipes would not break. It is because the water is imprisoned in the pipe behind the ice plug that the pipe must give way.

43. Expansion of Gases. — We found, from our study of expansion of liquids and solids, that they all expand at a different rate, making it necessary to have a table of coefficients of expansion. In the case of gases this is different, all gases expanding at the same rate. Therefore there is only one coefficient of expansion for all gases.

If a certain volume of gas be heated 1° C., it will expand $\frac{1}{273}$ of its volume at 0° C., if kept at the same pressure. This fraction, $\frac{1}{273}$, or .00366, is the coefficient of expansion of gases.

If 273 c.c. of oxygen, hydrogen, air, or any other gas, were heated from 0° C. to 1° C., the gas would expand $\frac{1}{273}$ of 273 c.c. = 1 c.c. Therefore the same amount of gas would fill a vessel of 274 c.c. at the new temperature, the pressure remaining the same.

44. Absolute Zero. — Gases, like all substances, are composed of molecules; but under normal pressure and temperature the molecules are comparatively far apart. It has been said that if the molecules of a gas, such as ordinary air, were magnified until they were the size of an orange, each molecule would be surrounded by a space equal to a cubic yard. If this is true, the space actually taken up by the molecules is very small, and the empty space about them is large.

When heat is applied, each molecule flies faster than usual, bumping its neighbors farther apart, thus making the space about it larger. If the gas is cooled, the molecules move more slowly than usual; and consequently come closer together. The more the gas is cooled, the more slowly the molecules move, until, theoretically, they come to rest. There is then absolutely no heat in the gas. When at rest they occupy so little space that it is not counted at all; and the gas is said to have no volume.

The temperature at which a gas has no volume is − 273° C. This temperature is then called *absolute zero,* because it means total absence of heat.

45. Charles' Law. — A man by the name of Charles formulated a law about the expansion of gases. This is called Charles' Law:

" *The volume of a gas at constant pressure is proportional to its absolute temperature.*"

Example: What is the volume of a gas at 70° C., if it occupies 800 c.c. at 20° C.?

Solution: The original *absolute temperature* is $20 + 273 = 293°$; and the final absolute temperature is $70 + 273 = 343°$. Since, by *Charles' Law,* the volume of a gas is proportional to its absolute temperature, the new volume is $\frac{343}{293}$ of 800 c.c. = 936.5 + c.c., or

$$\textit{new volume} = \frac{\textit{new absolute temperature}}{\textit{old absolute temperature}} \times \textit{original volume.}$$

46. Some Applications of Charles' Law. — The expansion of gases has much to do with the baking of bread, cake, or pie.

To make bread, yeast is used to produce the rising. The dough is mixed and allowed to stand in a warm place. The yeast plants grow and, in growing, give up carbon dioxide gas. The dough does not allow this gas to escape; so it forms bubbles in the dough, causing it to rise. The dough is then "worked down," and again allowed to rise in the same way. Usually it is "worked down" a second time and again allowed to rise. When it has risen properly, it is placed in a hot oven and baked.

Up to this time the rising has been caused by the growing yeast plants. But when it is put into the oven, the heat kills the yeast plants; so the rising after that is due to something else. The carbon dioxide bubbles in the dough are heated. According to Charles' Law, they expand $\frac{1}{273}$ of their volume at 0°C. for every degree Centigrade they are raised in temperature. This makes the bread rise while it is baking.

In baking biscuits and cakes, baking powder is used instead of yeast. But the action is the same. Baking powder, when wet, gives off carbon dioxide. The rising takes place as in the case of the yeast. Expansion also takes place when the cake or biscuits are placed in the oven.

In making pie crust there is usually nothing put into the dough to make it rise. But the crust must rise a little; or else it will be tough, instead of brittle and flaky. The expansion of gases is used to produce this rise. In mixing, the dough should be worked very lightly and the flour should be sifted in. Doing this gets air into the dough, and the light working leaves it there. Then if the dough is chilled by placing it in the refrigerator, the open spaces will fill up with cold air. This cold air will expand when the pie is baked, producing a brittle, flaky crust.

On the other hand, in clay modeling care is taken to work all the air out. The clay is kneaded and pounded and squeezed so that no air is left in it. If the air is not all out, when the piece is fired in the kiln these bubbles expand and break the piece of pottery.

Other applications of the expansion of gases, which will be studied under another topic, are: the draft in a stove, grate, furnace, chimney, range; hot-air heating; and ventilation.

CHAPTER III

HEAT TRANSFERENCE

47. Transference of Heat. — Heat is transferred from one place to another by three methods, *conduction*, *convection*, and *radiation*. Each of these will be taken up in detail.

48. Conduction. — If heat is applied to one part of a body, the molecules will be set into rapid vibration at that point. These molecules strike their neighbor molecules and set them in vibration. These in turn set the next ones going, and the heat travels along the body by *conduction*.

If one end of a poker is placed in the fire, that end gets hot, and all the rest of the poker is warmed. But the temperature is lower, the farther away from the end in the fire.

Different materials conduct heat at different rates. Those that conduct it very readily are called *good* conductors. Those that do not conduct heat readily are *poor* conductors, or are *good insulators*. Silver, copper, gold, aluminum, iron, and nearly all other metals are good conductors. Among the poor conductors, or good insulators, are asbestos, a vacuum, air space, water, paper, wood, glass, cloth, porcelain, horn, and ivory.

49. Non-conducting Handles for Cooking Utensils. — Figures 23, 24, 25, and 26 show different methods used to keep the handles of cooking utensils cool. The teakettle is made of metal, all except the handle, and that is made of wood. The metal becomes hot by conduction, but the wood does not let the heat through.

The coffee-pot and the percolator have handles of wood, porcelain, horn, or ivory, for the same reason. The stove-poker has a metal handle, but it consists of a wire wound in a coil about the end of the poker. This allows air space between the poker and the wire handle, and this air space is a good insulator.

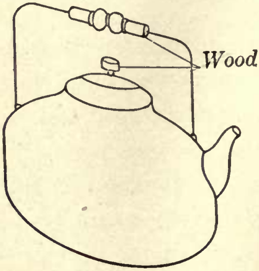

FIGURE 23. — WOOD HANDLES ON A TEA-KETTLE.

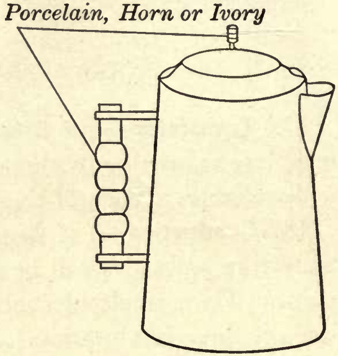

FIGURE 24. — THE HANDLES OF THE COFFEE-POT ARE INSULATED.

50. Good Conductor Bottoms on Utensils. — The bottoms of coffee-pots, tea-kettles, wash-boilers, etc., are usually of copper. This is for two reasons. First, copper will not corrode as readily as iron or tin; and therefore will keep cleaner and last longer. Second, copper is a good conductor, so that the heat is readily conducted from the gas flame or from the stove top to the contents of the utensil.

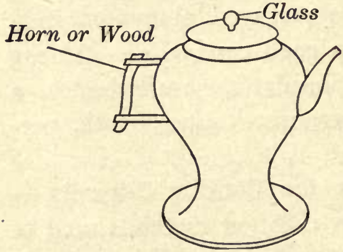

FIGURE 25. — INSULATION FOR THE HANDLES OF A PERCOLATOR.

51. The Fireless Cooker. — The fireless cooker is a box arrangement with non-conducting walls. Figure 27 shows how it is constructed. On the inside are pails in which the food is placed. Around the pails is the non-conducting wall. The food is first heated to the boiling point, and at the same time slabs of soap stone or iron are heated. When these are hot enough, the hot food is placed in the pails between the hot slabs; then the whole box is closed up tight.

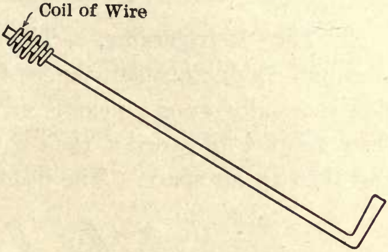

FIGURE 26. — COILED WIRE HANDLE ON A STOVE-POKER.

The non-conducting walls keep the heat in, so that the food stays up close to the boiling temperature without being supplied with more heat. This makes it necessary to use the fire only long enough to get the food and heating slabs hot.

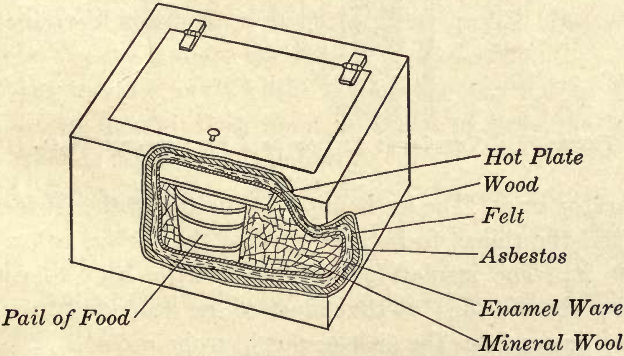

FIGURE 27. — THE FIRELESS COOKER.

The non-conducting material used may be wool, felt, mineral wool, asbestos, leather, paper, straw, shavings, or sawdust.

52. The Refrigerator. — The refrigerator (Figure 28) uses non-conducting substances for its walls. On the outside is usually wood; next is an insulating layer of paper; then another of wood; then a layer of asbestos or felt; and then an air space. The inside material is usually glass, enamel, or zinc. The ice is put into the top of the refrigerator, and the things to be kept cool on the shelves below or beside it. The insulating walls allow little heat to come in from the outside; so that most of the heat used to melt the ice comes from the articles put in to be cooled.

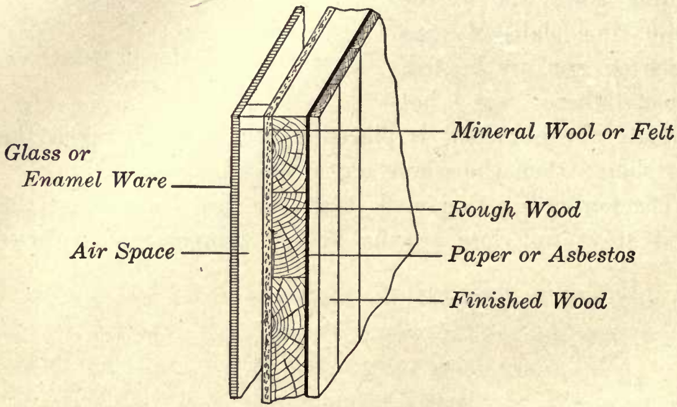

FIGURE 28. — THE CROSS SECTION OF A REFRIGERATOR WALL.

53. The Thermos Bottle. — The thermos bottle consists of a double glass flask with the outside silver-coated (Figure 29). The space between the walls of the flask is a vacuum, the air having been pumped out. The flask is then placed inside of an outer cover, which is either silver or nickel plated. An air space is left between the outer cover and the glass flask.

The bottle is used to keep liquids either cold or hot. When cold liquids are placed in it, the heat is kept out by the insulating walls; and if hot liquids are placed in it, the insulating walls keep the heat in.

The reasons for this are apparent. First, the glass walls of the flask are non-conductors, and do not permit heat to pass through them easily. Then, the vacuum is the best non-conductor there is. Also, the air space between the outside cover and the flask helps the insulation. Finally, the silvered and nickled surfaces have special uses, which will be discussed under the subject of Radiation.

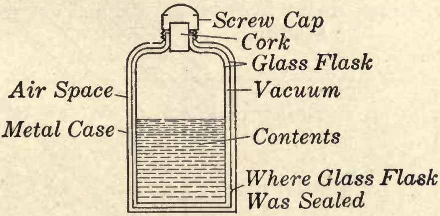

FIGURE 29. — CROSS SECTION OF A THERMOS BOTTLE.

Good thermos bottles will keep coffee too hot to drink for fifteen hours. Care must be taken to have the liquid hot when it is placed in the bottle.

54. Walls of Houses. — Walls of houses are so constructed that they do not allow the heat to pass through them readily. Either brick, stone or lumber is used. The lumber-made house is constructed as shown in Figure 30.

First is put up studding, which is about two inches by four inches. On the outside of this is nailed rough lumber, called *sheathing*. Over this is usually tacked heavy paper, and then the siding or weather-board. Inside the studding the plaster lath is nailed, and then the plaster is spread over this. This constitutes the complete wall, except for the wall paper usually placed on the inside.

Naming the insulating layers from the outside inward, they are, weather-board, heavy paper, sheathing, air space, plaster lath, plaster, and wall paper.

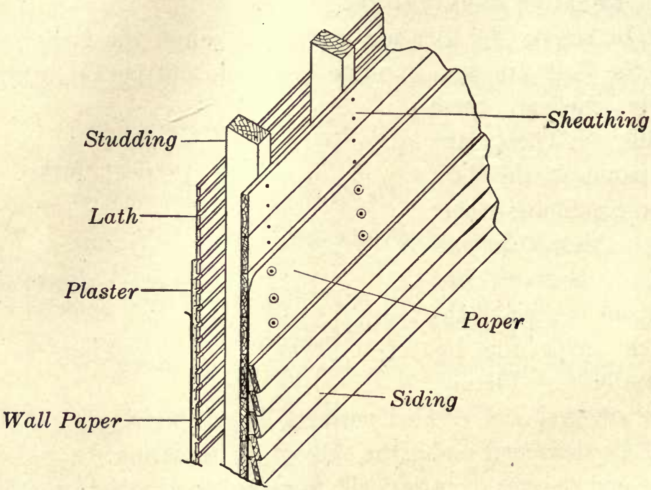

FIGURE 30. — CROSS SECTION OF THE WALL OF A HOUSE.

Sometimes in cold countries an extra set of lath and plaster is put in between the studding, making also an extra air space.

55. Clothes. — Winter clothing is usually made of nonconductors. We wear light cotton clothes in summer and heavy woolens in winter. Why? The cotton is compact and conducts heat readily, while the wool is loose in construction, containing many air spaces, which act as insulators. You can easily tell the difference between cotton and wool by dampening the thumb and finger and rolling a thread of each between them. The cotton will pack closely together, while the wool will spring back to its original looseness.

56. Convection. — Convection is the second method of transferring heat. In conduction we learned that it was the heat energy *only* that moved along. In convection, the heat passes from one place to another by means of material bodies carrying it.

Convection can best be understood by studying the following drawing. Figure 31 shows a section of air divided into columns. If a fire were built under column *ABCD*, the air would be heated and would consequently expand. As the air cannot push sidewise, on account of the other columns of air, when it expands it must push upward. This makes this column higher than the others; so the air flows outward over the other air columns at the top, as indicated by the arrows.

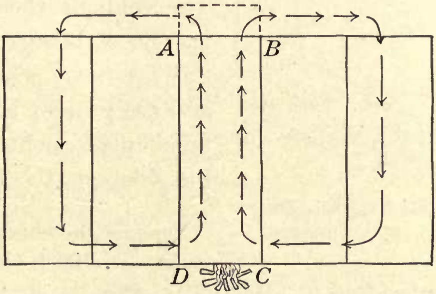

FIGURE 31. — DIAGRAM SHOWING HOW CONVECTION CURRENTS ARE SET UP.

Now this makes the columns at the side heavier than the middle one; so they crowd down, forcing some of the cold air under the middle column, as indicated by the arrows. This air will then be heated, will expand, and be pushed up by more cold air.

So the process goes on; the cold air flowing *towards* the warm area at the bottom, and the warm air flowing *away* from the warm area at the top. Over the warm area the air moves *upward,* while over the cold area the air moves *downward.* These movements are called *convection currents.*

Convection currents take place in liquids as well as in gases, but cannot take place in solids.

57. Drafts in Chimneys. — Drafts in chimneys are due to convection currents. A fire is started in the fire-box of the furnace. (Figure 32.) This warms the air, and causes it to expand and become lighter than the surrounding air. The cold air then pushes the warm air up the chimney and takes its place in the fire-box. This air is then heated, and the process is repeated, or rather it takes place continuously. The higher the chimney, the greater the draft.

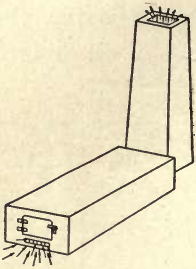

FIGURE 32. — DRAFT IN A CHIMNEY.

Suppose the chimney (Figure 32) were 4 ft. square and 100 ft. high; and suppose the air raised from 0° C. to 273° C., when the fire started.

$4 \times 4 \times 100 = 1600$ cu. ft. = volume of the chimney.

Now, air at 0° C. weighs .08 lb. per cu. ft.

$1600 \times .08 = 128.00$ lb. = wt. of air in the chimney, when air is cold.

Since a gas expands $\frac{1}{273}$ of its volume at 0° C. when heated 1° C., it will double its volume when heated to 273° C.

Therefore, since the chimney will contain only 1600 cu. ft., $\frac{1}{2}$ of the air must flow out.

$\frac{1}{2}$ of 128 lb. = 64 lb., wt. of air which remains in the chimney.

Now, since an equal volume of air on the outside weighs 128 lb., and inside it weighs 64 lb., the cold air outside pushes up on the warm air inside with a force of 64 lb. This shows definitely why the air rises in the chimney, or explains the draft.

58. Draft in a Kitchen Range. — Figure 33 shows the ordinary kitchen range. The air enters at the front and

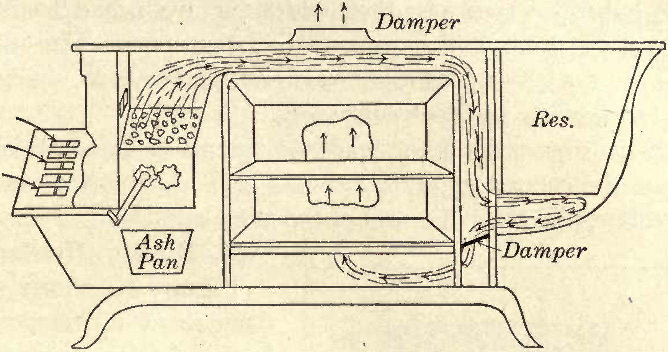

FIGURE 33. — DRAFT IN A KITCHEN RANGE.

goes up to the fire-box. Here it becomes hot and, with the smoke, passes up over the oven, down at the end and under

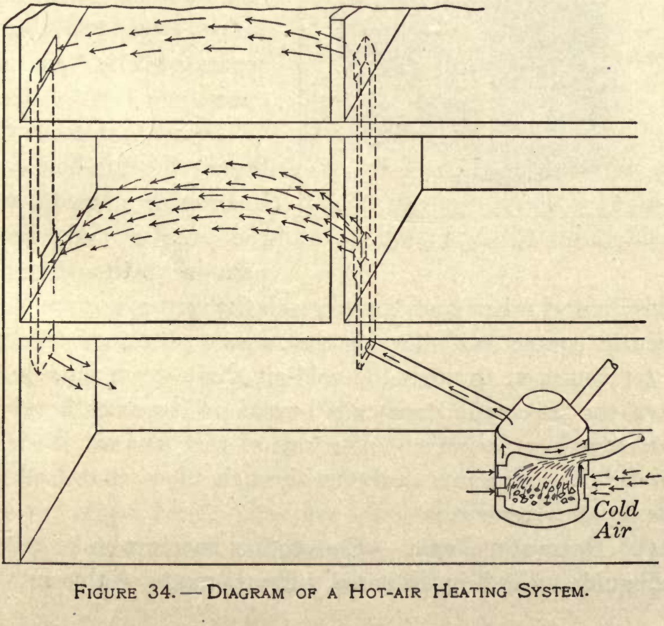

FIGURE 34. — DIAGRAM OF A HOT-AIR HEATING SYSTEM.

the hot-water reservoir, then under the oven, and finally up, at the back of the oven, to the stove pipe. Thus we see the hot gases pass completely around the oven, except in front, where the door is located.

If the oven is not to be used, the damper is closed, which shuts the current off from the oven and lets the hot gases circulate only under the top of the stove and the reservoir.

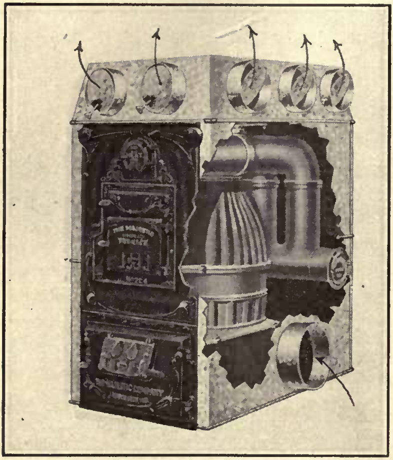

FIGURE 35.—A HOT-AIR FURNACE.

59. Hot-air Heating. — Figure 34 shows a diagram of the modern hot-air heating system. The furnace located in the basement consists of two parts, a fire-box, and a sheet-iron jacket, the two being separated by an air space.

The air that feeds the fire in the fire-box goes in through a hearth, and the smoke and gases pass on up the chimney. This air and other gases never reach the rooms, nor are they even in contact with the air that goes to the rooms. The latter comes in through the cold-air shaft (from outside or from the basement itself); is heated as it passes between the sheet-iron jacket and the wall of the fire-box; then is carried in convection currents through pipes that lead to the separate rooms.

60. Hot-water Tank. — Convection currents take place in liquids as well as in gases. Use is made of this in the hot-water tank. Figure 36 shows a hot-water tank designed to be heated by a separate heater, or by the furnace itself.

The water comes into the storage tank (*A*) through pipe (*f*). A pipe (*g*) comes out of the storage tank at the bottom and passes up through a pipe (*i*), around which is the heater (*B*). This pipe then returns to the top of the tank through (*h*). The pipe (*c*) is for drawing off the hot water to the places where it is needed.

A fire is started in the heater (*B*), causing the water in pipe (*i*) to expand. Convection currents are then set up, and the warm water flows over into the top of the tank, cold water coming in all the time at pipe (*g*). If the furnace (*C*) is going, the heater (*B*) is not needed, as the convection currents are set up through the coils in the furnace. When water is drawn off through (*c*), more water is supplied through the inlet, from the water main.

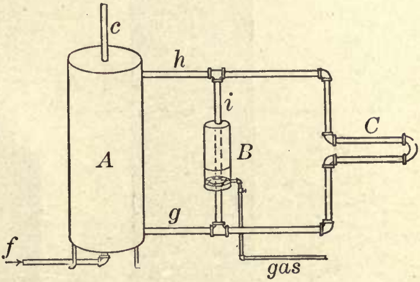

FIGURE 36. — DIAGRAM OF THE HEATING SYSTEM OF A HOT-WATER TANK.

If the water is allowed to get too hot, steam is generated, which may force the water back into the main, thus endangering the water meter.

61. Hot-water Heating System. — Figure 38 shows a modern hot-water heating system. The furnace is located in the basement, and has a boiler above the fire-box. From the *top* of the boiler, pipes are led off to the radiators in the different rooms. Returning from the other end of the radiators are pipes to bring the water back to the *bottom* of the boiler. The pipes going up to the radiators are called "risers," while those coming down are called "return pipes." Connected in the system is a pipe which goes up to the expansion tank, usually placed in the attic.

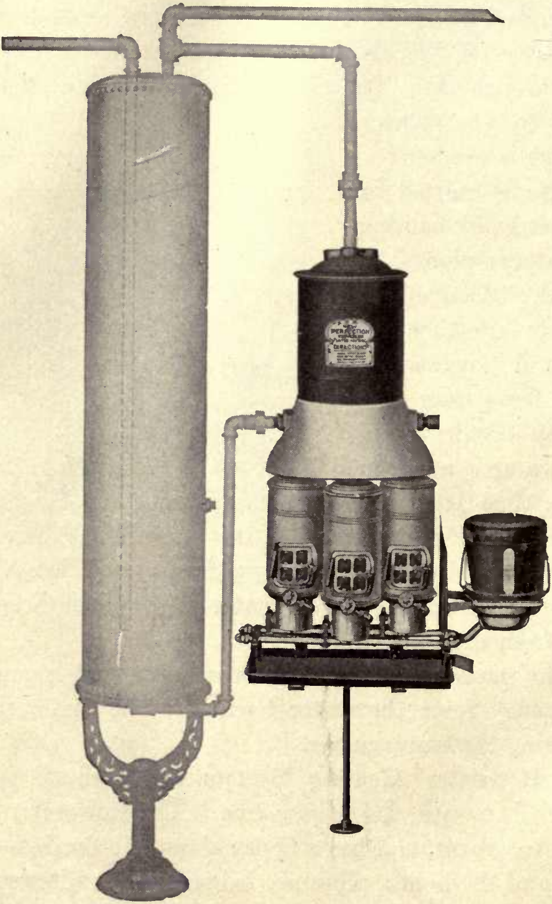

FIGURE 37.—A KEROSENE HEATER USED IN CONNECTION WITH THE HOT-WATER TANK.

Before the furnace is started, water is let in from the city main until the whole system is full and water rises into the expansion tank. Then the stop-cock is closed, so that no more water can get in or out. When the fire is started, convection currents are set up through the pipes, causing hot water to flow through the radiators.

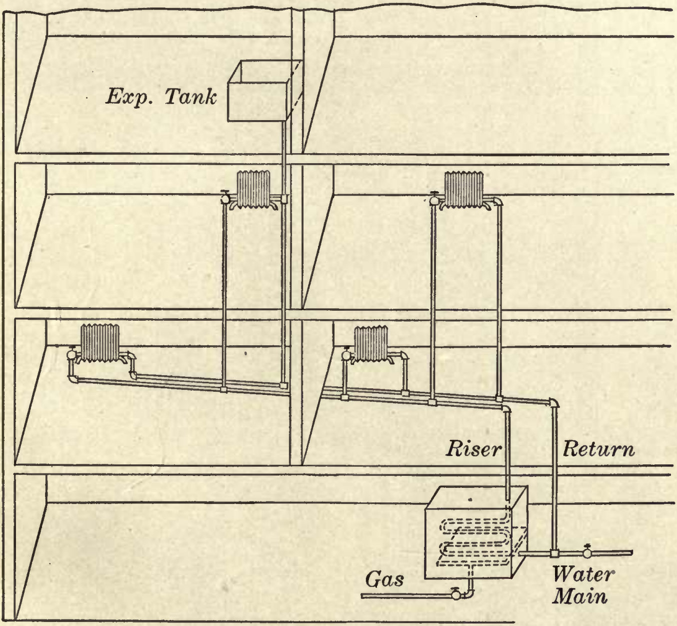

FIGURE 38. — DIAGRAM OF A HOT-WATER HEATING SYSTEM.

The expansion tank is to protect the pipes from bursting. If there were no place for the water to go when the fire is started, the expansion would burst the boiler or the pipes. This sometimes happens if the pipe to the expansion tank in the attic freezes.

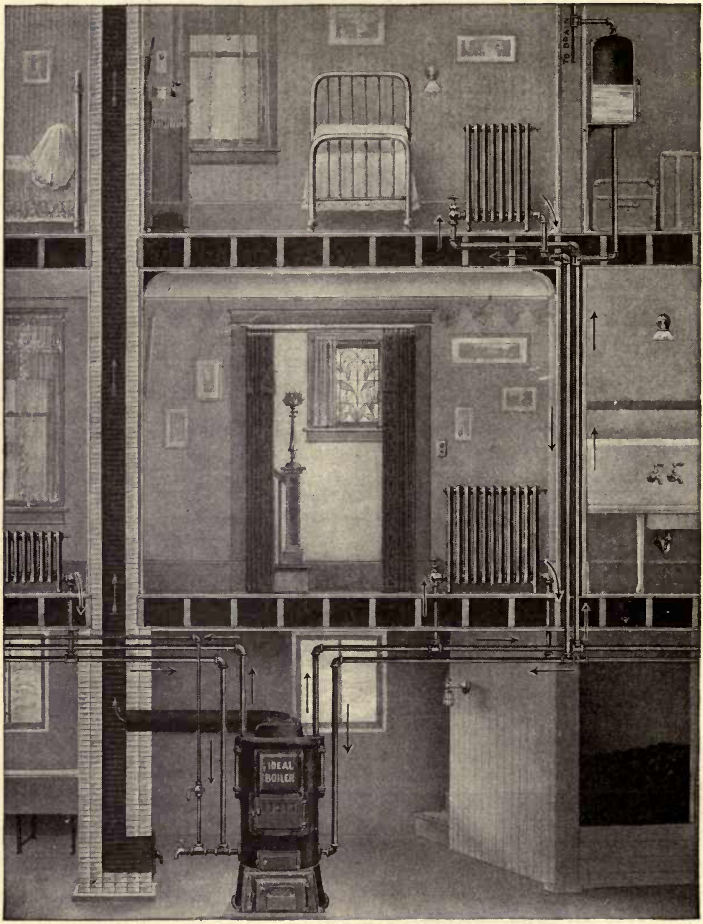

FIGURE 39.—A HOT-WATER HEATING SYSTEM INSTALLED.

62. Ventilation. — Ventilation is the supplying of pure air and the removing of impure air from rooms and buildings.

It is estimated that every person should have 3000 cubic feet of pure air per hour. There are two distinct types of ventilation — the *natural systems* and the *forced systems.*

In the *natural systems* convection currents are depended upon to change the air. In many dwelling houses no special means are used for ventilation; open windows, doors, or crevices are depended upon entirely to supply pure air.

If a window is opened both at the top and bottom, as is shown by Figure 40, and a lighted candle is held, first at the *bottom*, and then at the *top*, of the window, the candle flame will blow towards the room in the former position, but will blow outwards when held at the top, showing that air enters at the bottom and leaves at the top. This is explained by convection currents. Opening windows is a quick means of getting ventilation, but it produces drafts.

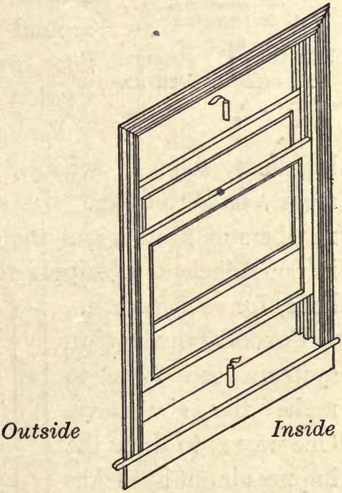

FIGURE 40. — VENTILATION BY MEANS OF THE OPEN WINDOW.

Even when the windows or doors are closed, air comes in around the frames, where there is not a perfect fit. This supplies pure air and is sufficient in many cases where very few people use the rooms. Wind coming from one side of the house often helps ventilate it, blowing pure air in on one side and forcing impure air out on the other.

A grate or fireplace is a good ventilator. Why?

One of the simplest methods for special ventilation is shown in Figure 41. A cold air vent is made just below the radiator. As the cold air comes in, it is heated by the radiator and made to flow to all parts of the room by means of convection currents. The impure air leaves by way of crevices.

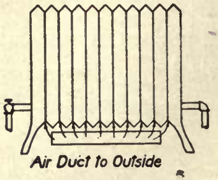

FIGURE 41. — ANOTHER METHOD OF VENTILATION.

Another of the natural systems is shown in Figure 42. Here the air comes in from the outside, passes around a special heating device in the floor, and then is distributed by convection currents.

Forced ventilation is used in large buildings, such as schools, apartment houses, department stores, and theaters. In such buildings there are great numbers of people, and the ordinary method of ventilation is not sufficient to supply the required 3000 cubic feet, per hour, for each person.

Forced-ventilation systems use fans to make the air move. One way is to draw the impure air out by means of fans, allowing the pure air to flow in to take its place. Other methods force the pure air in, driving the impure air out.

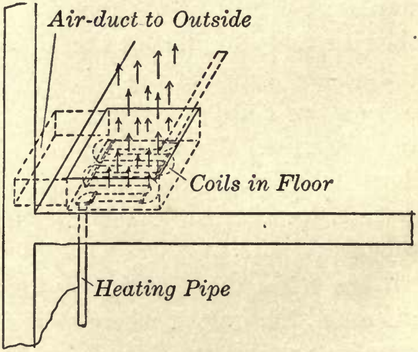

FIGURE 42. — VENTILATION WITH HEATING DEVICE IN THE FLOOR.

Figure 43 shows a forced-ventilating system in which the air is washed before it passes through the rooms. Pure air, forced in by the fan, enters the washing room. The washing room consists of a closed space in which water is kept spraying. Here the air has most of the dust and impurities removed. Then it is forced up the pipes to the heating space, and from there it goes to the places where it is needed.

63. Radiation. — Conduction and convection, the two methods of transference of heat which we have just studied, are easily understood; but the third method, radiation, is much more difficult to explain. We know that heat travels from the sun to the earth, and that it comes through space in the form of waves in the ether.

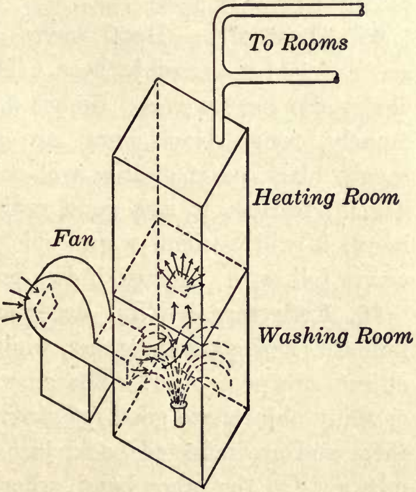

FIGURE 43. — DIAGRAM OF A FORCED-VENTILATING SYSTEM.

No one knows just what the ether is, but there are many facts which prove its existence. Whatever it is, it has no weight or body, but it fills the whole universe.

Heat in the form of waves in the ether is *insensible,* for *sensible* heat is due to the vibration of molecules.

When heat waves strike opaque objects, they are partly changed to sensible heat and partly reflected back as waves. When they strike transparent objects, such as air, glass, clear water, etc., they pass through without heating the object.

Radiation is the transference of heat by means of waves in the ether.

64. Radiators. — We must not get the idea that the sun is the only thing that sends out these heat waves, for all hot bodies do this, more or less. Any body that sends out heat waves is called a *radiator.*

All bodies at the same temperature do not radiate their heat at the same rate. It is found that rough, black bodies are the best radiators, while smooth, white, or shiny objects radiate heat very slowly.

65. Absorbers. — Heat waves striking opaque objects are changed to sensible heat. These objects are said to *absorb* the heat waves. Bodies which are good radiators, namely, rough black ones, are also good absorbers. A rough, black piece of iron will cool off quickly after it is heated, because it is a good radiator; and, on the other hand, it will become warm quickly if placed where heat waves fall on it, because it is a good absorber.

66. Reflectors. — Why are rough, black objects good radiators and good absorbers, while smooth, white, or shiny objects are poor ones? The answer is that smooth, white, or shiny objects are good *reflectors.* The heat waves fall on them and are reflected back, just as light is reflected by a mirror. On the other hand, when the heat waves start to leave the objects, the shiny surface turns them back again.

67. Applications. — In the thermos bottle (§ 53) the glass and the vacuum stop conduction and convection, but cannot stop the heat from radiating into or out of the bottle. This is stopped by the silver surfaces. As they are smooth, and shiny, any heat trying to radiate into the bottle is reflected out again; and any heat trying to radiate out is reflected in again. Therefore all three avenues for the transference of heat are stopped, so that either hot or cold liquids put into the bottle remain hot or cold.

A black, rough stove would be more serviceable than a bright, shiny one. Why? What kind of clothes would you wear in hot weather or in a warm climate? In a cold climate? Why?

Greenhouses trap the heat of the sun and do not let it out. The heat waves pass through the glass of the greenhouse and strike the plants and soil and other objects, which absorb the waves. In other words, the waves are changed to sensible heat. The glass walls are poor conductors; so the sensible heat cannot get out.

Dirty snow does not melt evenly, but in holes and patches. Soot and dirt, being black, absorb the sun's rays and thus melt the snow under them, causing holes in the snow. Where there is no dirt, the snow reflects the rays and therefore melts more slowly.

On a sunny day, would the snow melt faster under a black woolen blanket, or without the blanket? Would it be the same by night, or if the day were cloudy?

CHAPTER IV

SOURCES OF HEAT

68. Fuels. — We have studied the nature of heat, have seen what it will do, and how it is transferred from one place to another. Now comes the question, where do we get heat?

The sun is the great source of heat, but the sun's heat is so widely distributed and so little under our control, that it serves mostly the processes of nature, and for specific purposes of service we rely mainly on fuels.

Fuels are materials which will supply heat when burned. Sixty years ago the most common fuel was wood. What fuel do you use at home to keep warm and to do your cooking? Most of you will say gas, or coal.

There are two distinct kinds of gas — *natural gas* and *artificial gas*. The natural gas is forced directly from the gas well to your home. The artificial gas does not come from wells at all, but is made by baking soft coal and treating it in certain ways.

Natural gas is much better for heating purposes than artificial gas, since the natural gives 1200 B. T. U.'s per cubic foot, while artificial gas gives only half as much, or 600 B. T. U.'s per cubic foot.

There are many kinds of coal, but we usually speak of two, *hard* and *soft*. The hard coal is "clean," that is, it has little dust in it and gives off little smoke when it burns.

The soft coal is full of dust and its smoke is dense and sooty.

Hard coal yields about 14,000 B. T. U.'s per pound, when burned; while soft coal yields about 12,000 B. T. U.'s per pound. It is never possible to get all the heat when a fuel is burned, but more is available in some fuels than in others. This is true of coal. Hard coal would give only about 2000 B. T. U.'s per pound more than soft coal, if one could get all the heat. But a great deal more heat is lost in the case of soft coal than in the case of hard coal; so that, in the end, hard coal heats much better than soft coal.

FIGURE 44. — KEROSENE USED AS A FUEL IN THE COOK STOVE.

The following table gives a few of the materials used for fuels, and the name or kind of each. Opposite each kind of fuel is the heat value.

Sources of Heat

MATERIAL	KIND	HEAT VALUE
Coal	Hard	14000 B. T. U.'s per lb.
	Soft	12000 B. T. U.'s per lb.
	Coke	14000 B. T. U.'s per lb.
Wood	Hard	8400 B. T. U.'s per lb.
	Soft	8600 B. T. U.'s per lb.
Gas	Natural	1200 B. T. U.'s per cu. ft.
	Artificial	600 B. T. U.'s per cu. ft.
Oils	Kerosene	20000 B. T. U.'s per lb.
	Naphtha	20000 B. T. U.'s per lb.
	Crude Oil	18000 B. T. U.'s per lb.
Electricity		3411.72 B. T. U.'s per Kw. hr.

(Electricity is given in this table, though it is not a fuel.)

69. The Gas Meter. — The gas that you use is measured by a *gas meter*. The gas, flowing through the meter, moves little fans, making the hands move around on the dials.

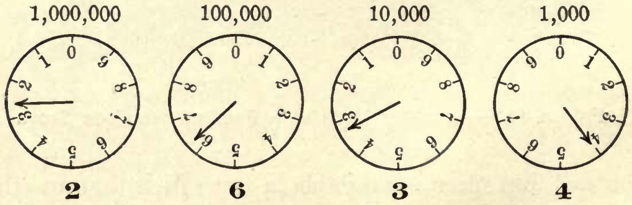

FIGURE 45. — DIALS OF A GAS METER SHOWING A READING OF 263,400 CU. FT.

These dials indicate how much gas has passed through the meter. The figures above the dials indicate the number of cubic feet that have passed when the hand makes *one complete revolution.*

Figure 45 shows a four-dial meter with a reading of 263,400 cu. ft.

Always begin to read from the right-hand side.

Your gas bill is made out from these meter readings. The meter man comes round every month and reads the meter. The last month's reading is subtracted from the present month's reading, and the number of thousand (M) cubic feet of gas used during the present month is thus determined. Only integral numbers of thousand cubic feet are counted. Thus, if the meter reads 263,400 cu. ft., the 400 is not counted, but the reading is called 263 M.

The cost of natural gas in Cleveland at present is 30¢ per M. while that of artificial gas is 80¢ per M.

Problems

1. How much hard coal is necessary to melt 150 lb. of ice when 12 per cent of the heat is available?

2. How much soft coal is necessary to heat 150 lb. of water from 40° F. to 100° F., only 6 per cent of the heat being available?

3. What will be the cost of the natural gas required to boil 10 lb. of water away, if 10 per cent of the heat is available? Natural gas costs 30¢ per M.

4. How many B. T. U.'s are given off when a ton of soft coal is burned?

5. What is the cost of boiling away 10 lb. of water, if artificial gas is used at 80¢ per M?

6. Draw a 4-dial gas meter showing a reading of 267,300 cu. ft.

7. What is the month's natural gas bill if the meter read 246,300 cu. ft. last month and 252,600 cu. ft. this month?

70. Heat from Foods. — The energy we use in the body comes from the foods we eat. In other words, our food is fuel. Part of the food is used for building and repairing tissue, but certain kinds are for fuel.

The United States Government has made charts of the building value and the heat value of most of our foods. A study of these charts is to be made at this point.

An average laboring man should have from 3000 to 3500 great calories of heat per day. A person not at manual labor should have less — it is estimated about 2500 great calories.

From the table in the Appendix, make up a day's menu so that the person shall get about 2500 calories. Figure the cost of each item and make a total for each meal. Calculate the cost for the whole day.

Review Problems

1. What is the nature of heat?

2. What is meant by the terms *hot* and *cold?*

3. Define temperature.

4. Change 25° F., – 16° F., 75° F. to the corresponding Centigrade readings.

5. Change 10° C., – 8° C., 80° C. to the corresponding Fahrenheit readings.

6. Define freezing point; boiling point.

7. Explain the effect of pressure on the freezing point; on the boiling point.

8. Name and explain two applications of the effect of pressure on the boiling point.

9. What are the three heat units used? Define each.

10. Discuss heat of fusion.

11. Discuss the refrigerator as an application of heat of fusion of water.

12. Discuss heat of vaporization.

13. Discuss the double boiler as an application of heat of vaporization of water.

14. Explain distillation.

15. What is meant by " iceless refrigeration "?

16. How many calories are necessary to melt 20 kg. of ice without changing its temperature? (One kg. = 1000 grams.)

17. How many B. T. U.'s are necessary to melt 50 lb. of ice? Where does the heat come from if the ice is in a refrigerator?

18. If the ice on a lake one mile square is $\frac{1}{2}$ foot thick, how many B. T. U.'s are necessary to melt it? (Assume that ice weighs 52 lb. per cu. ft. and is at 0° Centigrade.)

19. How many B. T. U.'s are given off when 6 lb. of steam condenses in the radiator?

20. Explain dew.

21. Define specific heat.

22. Name and explain two applications of specific heat.

23. Explain expansion.

24. How much will a 40 cm. glass tube expand in length when heated 20° C.?

25. How much larger than the rest of the glass will the bottom of a two-inch drinking glass become when the bottom is suddenly thrust into boiling water (212° F.)? (Assume that the original temperature was 80° F.) What will this expansion do to the glass?

26. Explain the thermostat.

27. Why do water pipes burst when they freeze?

28. What is the volume coefficient of expansion of a gas?

29. Explain the meaning of absolute zero.

30. What application has Charles' Law to the baking of bread and cake?

31. Explain conduction.

32. Give three applications of conduction as a method of heat transference.

33. Explain convection.

34. Why does the smoke flow out of a chimney?

35. Explain how the water is heated in the hot-water tank.

36. How long would the air in a room 20 ft. × 18 ft. × 10 ft. remain healthful if five persons were in it?

37. What are the two types of ventilation?

38. Discuss radiation.

39. Discuss radiators, absorbers, and reflectors.

40. Name and explain three applications of radiation.

41. What is a fuel?

42. How much natural gas is necessary to heat 100 lb. of water for a bath, if the water is at 38° F. at the beginning, and 100° F. when heated? (Assume that 8 per cent of the heat is available.)

43. How much soft coal is necessary to melt 50 lb. of ice, if only 6 per cent of the heat is available?

44. What is the cost per gallon of distilling water, if natural gas is used and 10 per cent of the heat is available? (Assume that the water has to be raised from 38° F.)

45. Why should the food one eats have a certain heat value?

CHAPTER V

WAVE MOTION

71. Examples of Wave Motion. — Sound and light are the commonest examples of wave motion; but the example most readily seen is the waves formed on water when something disturbs its surface. If a stone is thrown into still water, a splash occurs at the point where the stone strikes, and waves travel outward in all directions from this point. If a cork, or anything that will float, is placed on the water, it is seen to bob up and down; but it does not move away from its original position.

A similar example is the waves produced in a field of grain when the wind blows over it. The individual heads of grain merely rise and fall, but the wave travels across the field.

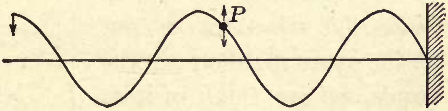

FIGURE 46. — WAVE IN A ROPE.

If a rope or rubber hose is held stationary at one end and the other end is shaken, waves will be sent down the rope. (Figure 46.) The waves travel from one end of the rope to the other, but each particle of the rope, such as *P*, jumps up and down, but does not move forward.

Figure 47 shows a spiral spring, attached to a support at the top, having its bottom suddenly jerked downward.

A portion of the spring *a* is stretched, but the rest of the coil *b* remains the same as before it was jerked. The next instant part *a* pulls down on part *b* and stretches *b*, letting *a* go back to its first position.

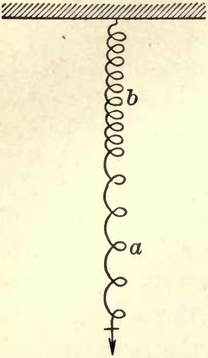

Figure 47. — Wave in a Spring.

This is a form of wave in which the waves move along the spring, and each particle of the spring jerks backward and forward, parallel with the spring. Waves can be sent along rubber bands just as along the spring mentioned above.

Suppose a rubber ball is in the center of the room, fastened by rubber bands to all the walls, the ceiling, and the floor. (Figure 48.) Then suppose the rubber ball contracts suddenly. All the rubber bands next the ball will be stretched, as shown in Figure 49. Each stretched portion will, in turn, stretch the next portion; and so on, until the effect runs out to the ends of all the rubber bands, just as it did in the spring. Since this effect travels out at the same speed in all the bands, we can think of it as being a wave like the wave on the water.

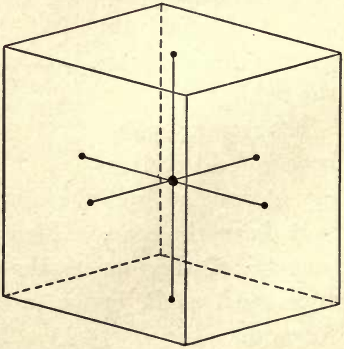

Figure 48. — A Rubber Ball Attached to the Sides of a Room by Means of Rubber Bands.

72. Origin of Waves. — It is seen from all the preceding examples that waves have to be started. This is always true. In the case of the water wave, the stone started the disturbance; in the field of grain, it was the wind; in the rope, your hand was the cause. The same thing was true with the spring; and the contraction of the rubber ball started the wave in the rubber bands.

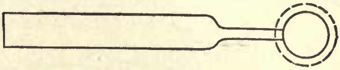

FIGURE 49.—A *Stretched* PORTION OF A RUBBER BAND NEXT THE BALL.

73. Transverse and Longitudinal Waves. — There are two motions in each case mentioned: the *motion of the wave,* and the *motion of the particles* of water, rope, spring, rubber, or grain heads. The relative directions of these two motions determine the kind of wave under consideration. *Waves in which the particles move at right angles to the direction in which the wave moves are called* ***transverse waves.*** (Figure 50.) The long arrow *W* indicates the direction of the wave, and the arrow *P* indicates the direction in which the particle moves.

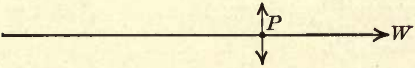

FIGURE 50.—SHOWING DIRECTIONS OF MOTIONS IN A TRANSVERSE WAVE.

Waves in which the particles move parallel with the direction in which the wave moves are called ***longitudinal waves.*** (Figure 51.) Here the two arrows are parallel, and so show a longitudinal wave.

FIGURE 51.—SHOWING DIRECTIONS OF MOTIONS IN A LONGITUDINAL WAVE.

74. Characteristics of Transverse Waves. — In case of the waves in the water, in the grain, and in the rope, we find that, as the waves follow one another, parts of the material are *high* and other parts *low.* The high parts *a* and *c* (Figure 52) are called *crests,* while the low parts *b* and *d* are called *troughs.*

The distance *ac* from one crest to a corresponding point in the next crest is called a *wave length;* or it may be from one trough to the corresponding point in the next trough, *bd*.

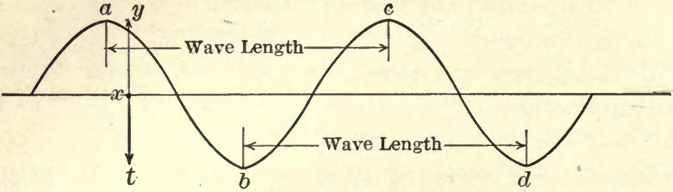

FIGURE 52. — CHARACTERISTICS OF A TRANSVERSE WAVE.

The distance that each particle moves from the position of rest is called the *amplitude, xy*.

When a particle has moved from *x* to *y*, to *t*, to *x*, it is said to have made one *complete vibration.*

The time required to make one complete vibration is called the *period;* and the number of vibrations the particle makes per second is called the *frequency*.

75. Characteristics of Longitudinal Waves. — In longitudinal waves we have very nearly the same characteristics as in transverse waves.

Instead of having *crests* and *troughs*, we have *condensations* and *rarefactions*. Figure 53 shows the particles as

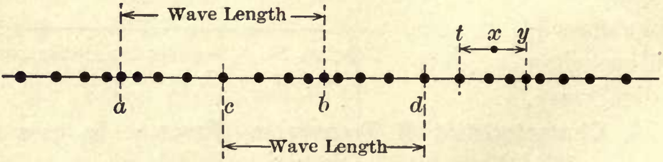

FIGURE 53. — CHARACTERISTICS OF A LONGITUDINAL WAVE.

they would appear in a rubber band if a wave were traveling in it.

The parts *a* and *b* where the rubber particles are crowded together, are called *condensations*. The parts *c* and *d* where the particles are stretched apart, are called *rarefactions*.

The *wave length* is the distance from one condensation to the next, or from one rarefaction to the next.

Amplitude, vibration, period, and *frequency* mean the same as in transverse waves.

76. How Transverse Waves Travel. — Most transverse waves travel in a substance which has tensile strength, that is, a substance which will resist a pull. The wave moves from one position to another in this way:

Figure 54 shows a wave in a rope, with some of its parts numbered. As the wave travels along the rope, the particles move up and down; or, as the particles move up and down, the wave travels along the rope. It is the motion of the particles that produces the wave motion.

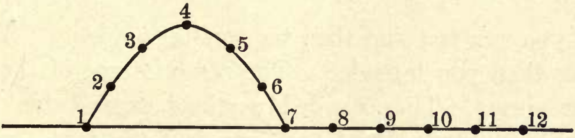

FIGURE 54. — THE START OF A TRANSVERSE WAVE.

In the figure, #1 has been to the top of the swing and has come back to its present position. Since #2 is on the same rope, it is *pulled* along after #1. Also, #3 is pulled by #2; and so on. Thus we see that the different particles are affected in a series, one after the other, and not all at once.

To state it as briefly as possible: the wave travels by one particle pulling the next one after it.

77. How Longitudinal Waves Travel. — Longitudinal waves may travel in substances that have tensile strength, but they do not depend on the *pulling effect* to make them travel. Instead, they depend on the *crowding effect*.

As an example, take the longitudinal wave in a spring. (Figure 55.) The particles of the spring are all crowded together at *d* and *e*, and are all spread out at *a* and *c*.

Now, since there is nothing to keep the spring stretched at positions *a* and *c*, and compressed at *d* and *e*, the crowded portions *d* and *e* will expand and tend to compress the parts *a* and *c*.

If this action should stop when the spring is everywhere stretched alike, the wave would stop; but it is the same as when you run fast and then try to stop suddenly. You go farther than you intended. The same is true of the parts of the spring. The crowded portions expand too much, causing an overstretched portion; and the part that was stretched before is compressed. In this way, the crowding effect is passed along, and the wave is said to travel.

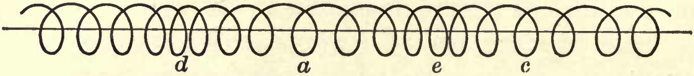

FIGURE 55. — HOW A LONGITUDINAL WAVE TRAVELS.

78. Velocity of Waves. — Waves travel at different speeds. If the rope is stretched tight, the waves will travel faster than if the rope is loose. They would travel more slowly if the rope were large and heavy.

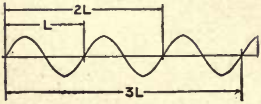

FIGURE 56. — VELOCITY = FREQUENCY × WAVE LENGTH.

On the other hand, the frequency of the vibration does not affect the speed of the wave, nor does the amplitude. If the frequency is high, the waves are *short;* but if the frequency is low, the waves are *long*.

During *one* vibration the wave travels 1 wave length, *L*. (Figure 56.) During *two* vibrations the wave travels 2 wave lengths, *2 L*; while during *three* vibrations it travels 3 wave lengths, $3\ L$. From this we see that in N vibrations the wave will travel NL.

Now, N is the number that usually stands for the frequency; so NL is the distance the wave will travel in 1 second.

The distance an object travels in a second is called its *velocity;* so the velocity of a wave is the *frequency times the wave length;* or

$$\textit{Velocity} = \textit{Frequency} \times \textit{Wave Length}$$
$$\text{or } V = NL.$$

CHAPTER VI

SOUND

79. Definition of Sound. — *Sound may be defined as a vibration of such a frequency that it may be detected by the ear.*

There are three things necessary for sound: (1) some vibrating object to start the vibration; (2) some medium to carry the vibration; (3) something to receive the sound.

The vibrating object to start the vibration may be a tuning fork, piano wire, bell, drum, etc.

The air is the medium which usually carries the waves from the vibrating body to the ear which receives it. Water will do this very well; and, in fact, any material body will carry the vibration. A vacuum will not. This can be shown by placing an alarm clock in a jar and then exhausting the air with a pump. The clock will become inaudible, but when the air is let in again it can be heard.

The thing that usually receives the sound is the ear, but sometimes the vibration is detected by other things.

80. Nature of Sound. — Sound waves travel through the air, but we cannot see the effect, since the air is transparent. Suppose that the air were made so we could see it, and that, just as a sound wave passed through it, an instantaneous photograph were made of the air. How would it look?

Figure 57 shows the condition of the air at a certain instant when a sound wave is passing through it. At the point, *a*, where the vibration started, the air is compressed. Around this the air is rare, *b*; still farther out, it is compressed, *c*; and it is again rare at *d*, etc.

If pressure gauges were placed around in different parts of the room while the sound-wave was passing, some would show high pressures while others showed low pressures. This is because the vibrations crowd the air together at some places and stretch it out at others. These places are in the shape of spheres. The spheres are alternately places of high and low pressures.

FIGURE 57. — A SOUND WAVE IN AIR.

We have described the air at an instant while the wave is traveling through it. The next question is, how do the waves travel?

Sound waves are longitudinal, and depend on the crowding effect for their motion. For example, in Figure 57, *a, c,* etc., are at high pressures; while *b, d,* etc., are at low pressures; so the air in the high pressures will push outward, crowding the air in the low pressures. This causes the air at the low pressures to become condensed, and form high pressures. In this way the high pressures travel outward. The low pressures follow in alternate order.

You will notice that each particle of air moves only backward and forward, while the wave always moves forward.

81. Velocity of Sound. — At 0° C. sound travels 1087 feet per second. Examples are common which show that sound waves take time to travel. You can always see the steam before you can hear the whistle. Often you can see a carpenter hit a nail and later hear the sound. As in the case of all waves, $V = NL$. This formula is used in finding the velocity of sound.

82. Effect of Temperature on Velocity of Sound. — You will notice that the temperature 0° C. was mentioned when the velocity of sound was given as 1087 feet per second. This is because a rise or fall in temperature changes the velocity of sound. A rise of 1° C. makes the velocity *2 feet per second greater;* and a fall of 1° C. makes the velocity *2 feet per second less.*

Thus at 20° C. the velocity will be $1087 + (2 \times 20) = 1087 + 40 = 1127$ feet per second.

Since a rise in temperature causes air to expand, at a higher temperature the air is less dense, and is thus more easily moved. This explains the change in velocity with a change in temperature.

83. Natural Free Period. — Any object such as a pendulum, a tuning fork, a swing, a string, etc. will vibrate with a certain period if allowed to swing freely. This period is called its *natural free period.*

84. Resonance. — In starting to swing some one, the push must always come at a certain time. The push must be in unison with the motion of the swing. This is called *resonance.*

Bridges can be set in motion if the even step of those crossing the bridge coincides with the natural free period of the bridge. For this reason, soldiers break step while crossing bridges.

One tuning fork will be set in vibration by another, if they have the same natural free period. This is true of all musical instruments.

The principle of resonance can be stated in this manner: *Any object free to vibrate will be set in motion by periodic disturbances coming in the natural free period of the object.*

85. The Ear. — The ear is the instrument with which we receive sound. The receiving is done in accordance with the principle of resonance. Figure 58 shows a section of the ear. The part (*a*) is that which we can see outside the head, and is called the *external ear*. From this a tube leads into the *middle ear* (*b*). Over the end of this tube is stretched a membrane (*d*) called the *ear-drum*. In the middle ear, attached to the ear-drum, is a series of three little bones. The last of these fits up against the end of a spiral tube called the *cochlea* or *inner ear* (*c*).

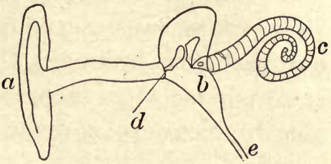

FIGURE 58. — DIAGRAM OF THE EAR.

The cochlea is a bony tube making two and one half turns like a snail shell. This tube is filled with a liquid; and stretched from one side to the other are about 7000 strings, all of different lengths, and ranging in frequency from about 16 to 10,000 vibrations per second. The tube (*e*) is the *eustachian tube*, which leads from the middle ear down into the throat.

86. How We Hear. — A sound wave consists of a condensation and a rarefaction, or a high and a low pressure. The external ear acts as a funnel and directs the sound wave into the tube to the ear-drum. When the high pressure strikes the ear-drum, the membrane is pushed inward, and then when the low pressure comes it is pushed outward. This sets the three bones in motion, and the small stirrup-shaped bone hammers on the opening to the inner ear. This makes the liquid in the shell-like tube vibrate the same as the air outside the ear. One of the 7000 strings — the one that has the same natural free period — will be set to vibrating by the principle of resonance.

Thus far the process is purely mechanical, and would take place whether the person were awake, asleep, or even dead.

To distinguish between different sounds, or even to become conscious of them, is a psychological process. Each of the 7000 strings has a nerve to the brain. Here it affects its own particular brain cell, thus making the person conscious of a sound. After many similar experiences the person is able to recognize a sound and distinguish it from other sounds.

If sounds of different frequencies come into the ear, the several corresponding strings will vibrate, and the person hears a combination of sounds.

87. Reënforcement, Interference, and Beats. — If two sound waves travel out together and are of different frequencies, they will *reënforce* one another at times, and *interfere* with one another at other times.

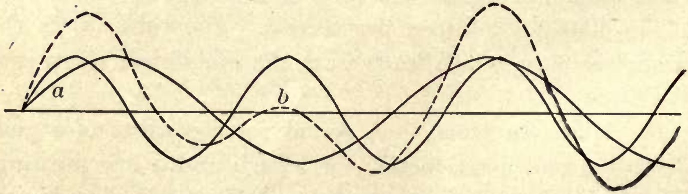

FIGURE 59. — REËNFORCEMENT, INTERFERENCE, AND BEATS ILLUSTRATED.

Figure 59 shows two waves of different frequencies starting out together. At *a* they are making condensations and rarefactions at the same time, and thus they increase the effect, or reënforce one another. At *b* one wave has vibrated faster than the other, and is making a rarefaction while the other is making a condensation. This is an attempt to make both a high pressure and a low pressure at the same place at the same time. The result is neither. One interferes with the other.

When the two waves reënforce one another, a loud sound is heard, and this is called a *beat*. A beat occurs every time one vibrating body gains one vibration on the other.

If the frequencies of the vibrating bodies do not differ by more than ten, the ear is able to distinguish the separate beats; but if they differ by more than ten, then the beats come so fast that the ear hears the series of beats as a *new sound*, and not as a series of separate sounds.

88. Characteristics of Sound. — Sounds differ from one another in three different ways. These differences are called the *characteristics of sound*, and are named *intensity*, *pitch*, and *quality*.

89. Intensity. — The intensity of sound means its *loudness*, and depends upon the amplitude of the vibration. A bell struck very hard with a hammer will give off a loud sound because the sides of the bell are made to swing with a large amplitude. As the amplitude gets smaller, the sound dies out and finally stops.

90. Pitch. — The pitch depends upon the frequency of the vibration. A string vibrating 256 times per second has a different pitch from one vibrating 384 times per second, even if they are struck with the same force. On the other hand, a string may be struck gently or hard, and it will always give off the same pitch. So the pitch is independent of the amplitude.

A pitch is said to be *high* or *low*, according to the frequency of vibration. The greater the frequency, the higher the pitch.

91. Quality. — The quality of a sound depends upon its *overtones.* The overtone is the thing which makes it possible to distinguish one person's voice from another's, or to tell the difference between a piano and a violin, etc.

92. Fundamental and Overtones. — When an object, such as a violin string, is giving its lowest tone, it is said to be giving its *fundamental.* The string vibrates back and forth as a whole, just like a rope that is being swung for some one to jump it. We are apt to think this is the only way a string will vibrate, but this is not true. The string will break up into segments which vibrate and in that way give off a higher tone. These higher tones are called *overtones.*

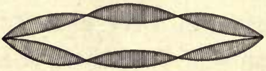

Figure 60. — Vibration of a String in Segments and also as a Whole.

A string may be giving several overtones and the fundamental at the same time. It is the presence of the overtones that changes the *quality* of the sound.

Figure 60 shows a string vibrating as a whole and also in segments.

93. Analysis of Sound Waves. — It has been known for many years that sound waves consist of fundamentals and overtones, but it is hard to tell just what overtones are present. In other words, it is hard to analyze a sound wave and tell just what waves it is made of.

During the latter part of the nineteenth century a scientist named Helmholtz succeeded in analyzing sound waves. He made hundreds of resonators (Figure 61), all of different sizes, ranging from about a half-inch in diameter to several feet in diameter. By testing a certain sound with each of these hundreds of resonators he was able to determine which ones were in tune with that sound. The ones that had the same free period vibrated; the others did not.

The most recent and most successful attempt to analyze sound waves was made by Dr. Dayton Miller of Case School of Applied Science, who is still working on the problem. He has made a machine which will transform the sound waves into a vibrating ray of light, so that the wave can be thrown upon a screen and seen with the eye. He also throws this ray on a photographic plate and takes a picture of the wave, making it possible to study the wave at leisure.

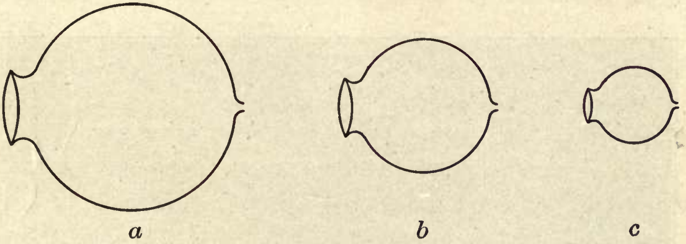

FIGURE 61. — HELMHOLTZ RESONATORS.

Dr. Miller is now perfecting another machine, which will analyze the wave after it has been taken on a photographic plate. When this is successfully accomplished, he will be able to take any sound wave and tell how many and what overtones are present.

With Dr. Miller's machine the differences between singing voices are easily seen. Some singers have many harmonious overtones, while others have very few.

Figures 62, 63, 64, and 65 show samples of waves given by different singers.

94. Laws of Vibrating Strings. — The pitch of a string may be changed in three ways: by changing (1) its length, or (2) its tension, or (3) its diameter. The tighter it is, the

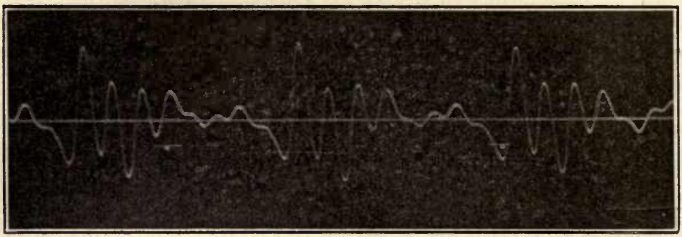

Figure 62. — Photograph of Sound Wave Produced by Speaking the Vowel "a" as in "Father."

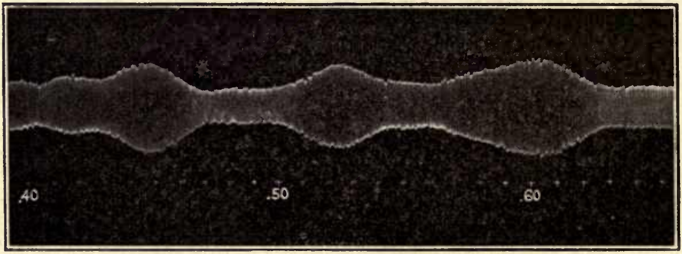

Figure 63. — Photograph of Sound Wave Produced by the Soprano Singing Alone in the Sextet from "Lucia."

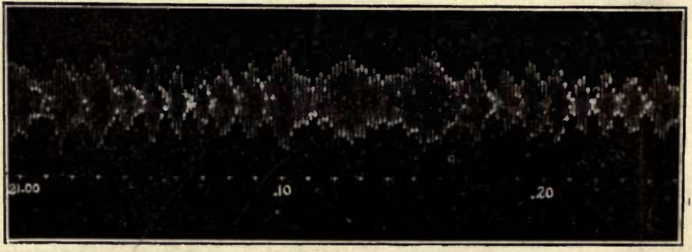

Figure 64. — Photograph of Sound Wave Produced by the Soprano and Baritone Singing Together in the Sextet from "Lucia."

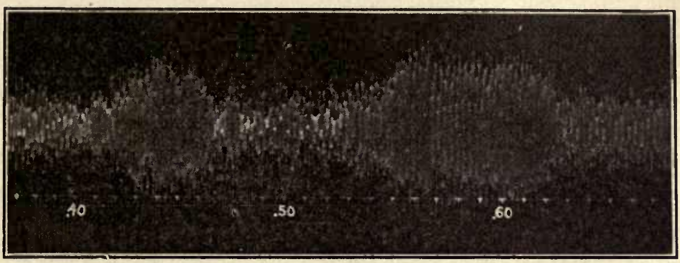

Figure 65. — Photograph of Sound Wave Produced by All Six Singing Together in the Sextet from "Lucia."

faster it vibrates; the longer it is or the thicker it is, the slower are its vibrations.

The laws concerning these three things are stated as follows:

(1) The diameter and tension remaining the same, the frequency of a string varies inversely as its length.

(2) The length and tension remaining the same, the frequency of a string varies inversely as the diameter.

(3) The length and diameter remaining the same, the frequency of a string varies directly as the *square root* of the tension.

95. Resonance in Closed Pipes. — If a tuning fork is struck and then held over a pipe closed at the bottom, the pipe will reënforce the sound of the fork, provided that the tube is of the proper length.

When the fork moves from *a* to *b* (Figure 66), a condensation is made in front of the fork and travels down the tube to the bottom and back to the mouth again, while the fork moves down to *b*. At this instant the fork

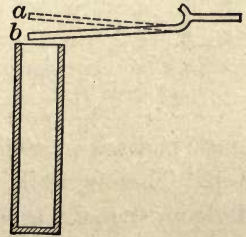

Figure 66. — Resonance in a Closed Pipe.

starts back toward *a,* forming another condensation in front of the fork; but since a condensation is already coming out of the tube at this instant, this forms a *double condensation,* making a loud sound.

In the same way the rarefactions are reënforced. This action will take place only when the tube is of the proper length. The reflected condensation must be just coming out of the tube when the fork is ready to flip back from *b* to *a*; and the reflected rarefaction must be coming out when the fork is ready to flip back from *a* to *b*.

Now, since a condensation travels down and back, or *twice* the length of the tube, while the fork goes from *a* to *b*, or *one half* vibration, the sound will travel *four times* the length of the tube during a whole vibration. Therefore the closed pipe is *one fourth* wave length.

By this method the velocity of sound may be determined. The wave length is found by multiplying the length of the tube by *four*. The frequency is always marked on the fork. Then, by formula:

$$V = NL.$$

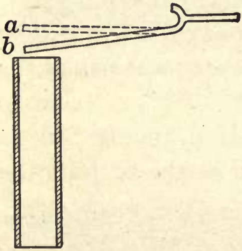

FIGURE 67 — RESONANCE IN AN OPEN PIPE.

96. Resonance in Open Pipes. — If the pipe is open instead of closed at the bottom (Figure 67), the condensation will travel down to the end, and will then return a *rarefaction* instead of a condensation; so the fork must be back at *a* again before this rarefaction gets to the top. That is, while the sound travels down and back, the fork must make a complete vibration. Therefore the pipe is *one half* wave length.

CHAPTER VII

BASIS FOR MUSIC

97. Music and Noise. — The prime difference between music and noise is that in *music* the sounds have rhythm while in *noise* they do not. By rhythm is meant that the sounds come at regular periodic intervals.

The music of the savages consists almost entirely of beating time, while the music of civilized people goes farther than this, and consists of rhythm and *harmony.*

98. Harmony. — Two or more tones are said to be in harmony if their combination is pleasant to hear. *Harmony,* then, *is the combining of musical tones, according to given laws, so that they will be pleasing to the ear.*

One of the laws of harmony is, *the ratios of two tones must be in a simple ratio if they are to be in harmony.* By " simple ratios " is meant, such ratios as $\frac{1}{1}$, $\frac{2}{1}$, $\frac{3}{2}$, $\frac{4}{3}$, $\frac{5}{4}$, $\frac{6}{5}$, $\frac{3}{1}$, $\frac{5}{3}$, etc.

The reason why tones having their frequencies in simple ratios are harmonious is a matter of supposition. It is supposed that the mind likes *system,* and, more than that, *simplicity of system.* The most simple method in which soldiers can march is *in step;* the next simplest is every other soldier making *two steps* to his neighbor's *one;* the next is *three* steps to *two;* and so on. As soon as the ratio gets into large numbers, the mind fails to grasp the system, and the marching soldiers become a mob.

The same is true of sound. When the ratios are simple, the mind grasps the relation and is pleased; but when the ratios become complex, the mind fails to detect any relation whatever, and a *discord* results.

99. Major Triads. — When the frequencies of three tones are in the ratio 4 : 5 : 6, those three tones are called a *triad*. In music there are three triads, called *major triads*. They are:

1. Tonic – C, E, G
2. Dominant – G, B, d_2
3. Subdominant – F, A, c_2

100. Major Scale. — The eight notes which form the major triads, when arranged in the proper order, form what is called the *major scale*.

$$C\ D\ E\ F\ G\ A\ B\ c_2$$

The frequency of each of the tones in the major scale can be found by the ratios of the major triads.

$$\left.\begin{matrix} C:E:G \\ G:B:d_2 \\ F:A:c_2 \end{matrix}\right\} = 4:5:6$$

The frequency of C can be taken as any number, and then the frequencies of each of the others can be determined from it.

If $C = 256$ $\qquad$ $C = 256$

$$\frac{E}{C} = \frac{5}{4} \qquad \frac{G}{C} = \frac{6}{4}$$

$$E = \frac{5}{4} \cdot \mathrm{C} \qquad G = \frac{6}{4} \cdot \mathrm{C}$$

$$E = \frac{5}{4} \cdot 256 = 320 \qquad G = \frac{6}{4} \cdot 256 = 384$$

By this method the frequencies of all notes can be found. Construct the major scale and calculate all the frequencies.

101. The Musical Interval. — The ratio of the frequencies of any two tones is called the *musical interval* between those tones.

The musical intervals between consecutive tones in the octave, and the intervals between each tone and C are given as follows:

Letter	C	D	E	F	G	A	B	c_2
Frequency	256	288	320	$341\frac{1}{4}$	384	$426\frac{2}{3}$	480	512
Interval between consecutive tones . .		$\frac{9}{8}$	$\frac{10}{9}$	$\frac{16}{15}$	$\frac{9}{8}$	$\frac{10}{9}$	$\frac{9}{8}$	$\frac{16}{15}$
Interval between each tone and C . . .	1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2

There are a few musical intervals of more importance than others, and these are given special names. Thus $\frac{1}{1}$ = *unison;* $\frac{3}{2}$ = a *fifth;* $\frac{4}{3}$ = a *fourth;* $\frac{5}{4}$ = a *major third;* $\frac{25}{24}$ = a *half step;* and $\frac{2}{1}$ = an *octave.*

102. The Chromatic Scale. — For certain purposes it is often advisable to start triads on other notes than C, G, and F. This requires other notes than those in the major scale. By starting triads on each of the other notes of the major scale we have:

$$\left.\begin{array}{l} D : X_1 : X_2 \\ E : X_1 : X_2 \\ A \ \ X_1 : X_2 \\ B : X_1 : X_2 \end{array}\right\} = 4:5:6$$

Figuring out the frequencies of these unknown notes, we find they are in the first triad:

$$\frac{X_1}{D} = \frac{5}{4};\ X_1 = \frac{5}{4} \cdot 288 = 360$$

$$\frac{X_2}{D} = \frac{6}{4};\ X_2 = \frac{6}{4} \cdot 288 = 432$$

Now, 360 falls between *F* and *G*, and 432 falls between *A* and *B*; so they are called *F-sharp* and *A-sharp*, respectively. Thus the first triad is *D*, *F-sharp*, and *A-sharp*.

When all these unknown frequencies are calculated, it is found that there are *five new notes* which fall in between the other notes of the major scale, and a new scale is built up, using the major scale, with the five new notes added in their proper places. This new scale is called the *chromatic scale.*

The notes in it are:

C, C-sharp, D, D-sharp, E, F, F-sharp, G, G-sharp, A, A-sharp, B, c_2.

103. Tempered Scale. — The musical intervals between the consecutive notes in the chromatic scale are not all equal. But in the piano and similar instruments the notes are *made* at equal intervals. This new scale is called the *tempered scale.* The musical interval between consecutive notes is

$$\sqrt[12]{2} = 1.095$$

This musical interval is calculated by this method:

There are *twelve* equal intervals in the tempered scale. Suppose we let x equal the numerical value of this interval.

$$\begin{aligned} \text{Then } C\text{-}sharp &= C \cdot x \\ D &= C\text{-}sharp \cdot x = C \cdot x \cdot x \\ D\text{-}sharp &= D \cdot x = C \cdot x \cdot x \cdot x. \end{aligned}$$

And so on for the complete scale.

$$\begin{aligned} \text{Therefore } c_2 &= C \cdot x^{12}; \\ \text{but } \qquad c_2 &= C \cdot 2. \\ \text{Therefore } x^{12} &= 2, \\ \text{or } \qquad x &= \sqrt[12]{2}. \end{aligned}$$

104. Standard Pitch. — In order that a piece of music may be played as intended, there must be a standard pitch for C. There are several standards, the commonest being the "International Standard Pitch," which makes $C = 261$.

105. Musical Instruments. — The student is here asked to report on *one* musical instrument, covering the following points:

1. *Description of the instrument.*
2. *How the sound is produced.*
3. *How the pitch is determined.*
4. *What the principal use of the instrument is.*

Review Problems

1. Give five examples of wave motion.

2. Distinguish between transverse and longitudinal waves.

3. What are the characteristics of transverse waves? Define each.

4. What are the characteristics of longitudinal waves? Define each.

5. Explain how transverse waves travel.

6. Explain how longitudinal waves travel.

7. If a rope be shaken at the rate of 3 vibrations per second, and the waves are 10 feet long, how fast do the waves travel?

8. Explain the nature of sound.

9. If 3 seconds after you see the lightning you hear the thunder, how far away was the lightning? Take the temperature as 18° C.

10. Why does a vase, or any other small article in the room, often rattle when the piano is played?

11. Why is it dangerous for the audience to stamp the feet in a large auditorium?

12. Describe the ear.

13. How do we hear?

14. Why do heavy explosions, such as the firing of cannon, often cause deafness?

15. What are beats?

16. What is the cause of "dead points" — places where it is difficult to hear — in an auditorium?

17. Name the characteristics of sound. Upon what does each depend?

18. What is the difference between a "sweet" and a "harsh" voice?

19. If two strings are the same, except that one is 40 cm. long and the other is 60 cm. long, what is the ratio of their frequencies? If the 40-cm. string vibrates 300 times per second, what is the frequency of the other?

20. Why are some of the strings on a piano large and others small?

21. How does a piano tuner tune a piano? Why does this change the pitch?

22. Why does a pipe organ have many pipes, all of different lengths?

23. Explain how to find the velocity of sound.

24. What is rhythm? Harmony?

25. What is the reason why tones must be in simple ratios to be in harmony?

26. Construct a major scale, using *C* as 96.

27. Construct a chromatic scale, using *E* as 400.

28. What is the tempered scale?

29. Why is the common musical interval between consecutive notes in the tempered scale 1.059?

30. Name two other standard pitches besides the International Standard Pitch. (Outside reference.)

31. What is the use of the sounding board in a piano?

32. Why does a phonograph give a higher pitch when run fast?

33. What changes the pitch of a slide trombone?

34. What changes the pitch of a cornet?

35. Why does the piano have the tempered scale? Figure out the frequencies of all notes on the piano, using *A* as 435.

CHAPTER VIII

LIGHT

106. Nature of Light. — Nobody knows the exact nature of light. Many theories have been offered, but none has been accepted as final. But we know a great deal about light, even if we do not know just what it is. In this discussion, we shall take up facts already proved and mention some of the latest theories.

It is definitely known that light is one of the many forms of *energy*, and that it has much in common with radiant heat.

107. Theory of Production of Light. — In almost all cases, light is produced by something hot. (*Fluorescence* and *phosphorescence* are exceptions.) Our common sources of light are the sun, a fire, a candle, a lamp, or some other very hot body.

It is thought that the rapid vibration of the molecules of the heated body sets up waves in the ether, and that the ether transmits these waves through space. These waves are of different lengths, depending upon the frequency of the vibration of the molecules. Those waves which are of the right length to affect the eye are called *light*.

When a piece of iron becomes hot enough, it gets *luminous;* in other words, it gives off light. The molecules of the iron vibrate very rapidly, and this vibration sets up waves in the ether, which are transmitted in all directions. These waves we call *light*.

108. Propagation of Light Waves. — Just how the ether transmits these waves is still a mystery, but it is known that they are transverse, and that they travel in *straight lines.*

109. Velocity of Light. — It is easy to find examples showing that sound takes time to travel, but all ordinary examples fail to show that the same is true of light, and for many centuries the transmission of light was thought to be instantaneous.

110. Roemer's Method of Finding Velocity of Light. — The first man to prove that the passage of light requires time was Roemer, and he did it by accident.

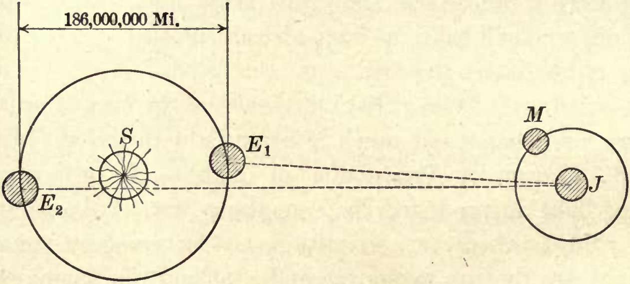

Figure 68. — Relative Positions of Sun, Earth, Jupiter, and Moon of Jupiter.

Roemer was an astronomer who lived during the seventeenth century. About 1676 he was studying the eclipses of one of the moons of Jupiter by Jupiter. He found that the eclipses did not occur at regular intervals, as was expected, but that for six months the time between eclipses became shorter and shorter, and then for the next six months it became longer and longer. (Figure 68 shows the relative position of the heavenly bodies under consideration.)

Every time the moon of Jupiter came into the shadow of Jupiter, there was an eclipse. Roemer knew how long it took the moon to make a complete revolution about Jupiter, and so assumed that eclipses ought to come at that interval. He made a schedule something like the following (assuming that it takes exactly 30 days for the moon to make a revolution):

1st	eclipse	12 o'clock	Jan. 1
2d	eclipse	12 o'clock	Jan. 31
3d	eclipse	12 o'clock	Mar. 1
4th	eclipse	12 o'clock	Mar. 31
5th	eclipse	12 o'clock	Apr. 30
6th	eclipse	12 o'clock	May 30
7th	eclipse	12 o'clock	June 29
8th	eclipse	12 o'clock	July 29
9th	eclipse	12 o'clock	Aug. 28
10th	eclipse	12 o'clock	Sept. 27
11th	eclipse	12 o'clock	Oct. 27
12th	eclipse	12 o'clock	Nov. 26
13th	eclipse	12 o'clock	Dec. 26

The earth being at E, at the time of the first eclipse, Roemer found that at each occurrence the eclipses were behind the schedule more and more, and that six months later, when the earth was at E_2, the eclipse occurred 1000 seconds later than the scheduled time (12 o'clock, June 29). Then, for the next six months, the eclipses began to catch up with the schedule, and were exactly on time (12 o'clock Dec. 26) when the earth got back to E_1.

Roemer then reasoned that it took the light 1000 seconds to cross the earth's orbit, a distance of 186,000,000 miles. This gave the velocity of light as $\frac{186,000,000}{1000} = 186,000$ miles per second.

111. Comparative Value of Velocity of Light. — The velocity of light, 186,000 miles per second, is so great that the mind cannot appreciate it without some comparative values. It means that a ray of light would travel nearly 7½ times *around the earth* in one second. It would take a train, going at 60 miles an hour, over 4 months to travel as far as a ray of light can travel in *one second.*

112. Shadows. — Since light travels in straight lines and will not go through opaque objects, it is easily shut off by putting one of these objects in its path. When light is shut off from a certain space by an object placed in the path of the light, that space is called a *shadow. A shadow is the space from which the light has been cut off.*

A man walking on the sidewalk on a sunny day casts a shadow. Hold your hand in front of a lamp and your hand casts a shadow. The earth shuts off part of the sun's rays and casts a shadow.

The shadow in each of these cases is the *space* back of the object. It is not, as we often think, the dark portion of the sidewalk or of the wall. Those are only cross sections of the shadows.

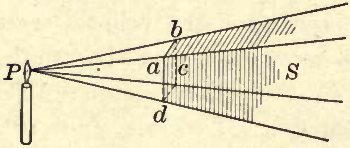

FIGURE 69. — SHADOW FROM A POINT SOURCE OF LIGHT.

113. Shadow from a Point Source of Light. — Figure 69 shows a shadow cast by an object in front of light coming from a *point source.*

The light travels out in all directions from point *P*, but that which strikes the rectangle *abcd* is shut off, thus making the space *S* without light, or a shadow. The shadow, then, is a pyramid with the top cut off.

Had the object been circular, the shadow would have been a cone with the top cut off.

114. Shadow from a Large Source. — Most of our light comes from large sources and not from points. Figure 70 shows the shadow cast by an object (O) with a large source of light (S).

It will be seen that the space above bc and below ad is lighted by all of S. The space between ac and bd beyond the object gets no light at all, and so is totally dark. This is called the *umbra* (U). The space outside the umbra, and still inside ad and bc, is called the *penumbra* (P, P). This space is totally dark at ac and bd, but becomes lighter and lighter, as you go outward. That is, point y has more light than point x, because more of S is shining on it.

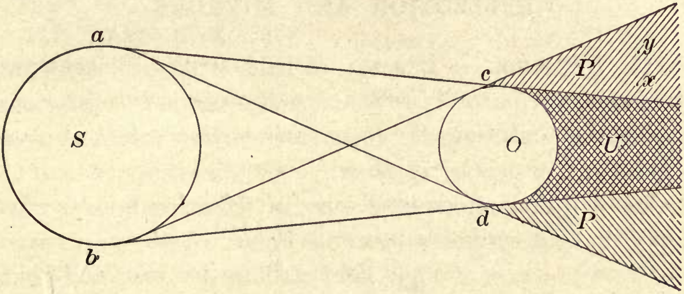

FIGURE 70. — SHADOW FROM A LARGE SOURCE OF LIGHT.

Shadows play a great part in the arts both of painting and of sculpture. They also enter into the problems of proper illumination, and so will be further discussed under that topic.

CHAPTER IX

REFLECTION AND MIRRORS

115. Reflection. — If a ray of light strikes a bright surface, it will be partially reflected. *Reflection is the returning of a ray of light into the same medium from which it came, when it strikes another medium.*

One of the most common cases of reflection is seen when a ray of light strikes a mirror. Figure 71 shows a ray of light striking a mirror and being reflected.

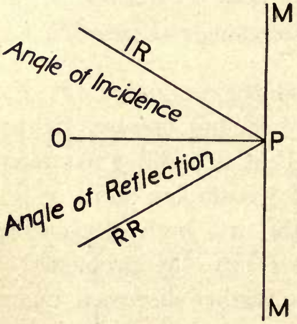

FIGURE 71. — SHOWING REFLECTION OF A RAY OF LIGHT.

IR is the *incident ray*. *RR* is the *reflected ray*. *MM* is the mirror, and *OP* is the perpendicular to the mirror at the point where the ray *IR* strikes the mirror.

The angle between the incident ray and the perpendicular to the mirror is called the angle of incidence.

The angle between the reflected ray and the perpendicular to the mirror is called the angle of reflection.

Light is always reflected so that the angle of reflection equals the angle of incidence. This is called the *Law of Reflection.*

116. Pencil of Rays. — So far we have spoken of *rays of light.* Light never goes in *single rays,* but in *bunches of* *rays*. A small *bunch* of rays is called a *pencil of rays*, and this is what we have to consider instead of single rays. A person gets a pencil of rays, or many pencils of rays, in his eye, instead of just single rays. (Figure 72.)

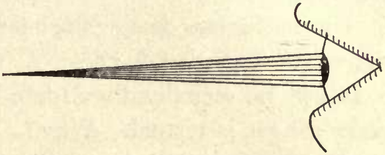

FIGURE 72. — A PENCIL OF RAYS.

117. Image in a Plane Mirror. — Figure 73 shows the image in a plane mirror. The object is *ab*; *MM*, the mirror; and *a′b′*, the image. *An image is the space occupied by what is apparently the object itself.*

Rays are sent off in all directions from each point of the object. Let us consider the two points *a* and *b*, the *head* and *tail* of the object. There is just one pencil of rays from each of these points which goes out, strikes the mirror at the right angle, and is reflected into the eye.

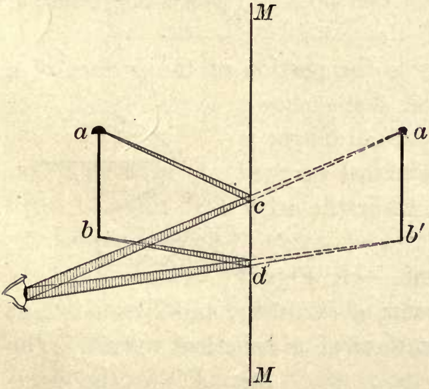

FIGURE 73. — CONSTRUCTION OF AN IMAGE IN A PLANE MIRROR.

The pencil of rays coming from *a*, after being reflected at *c*, appears to come from point *a′*; and the pencil of rays coming from *b*, after being reflected at *d*, appears to come from *b′*.

By geometry it is easily proved that *the image is as far back of the mirror as the object is in front, and on a line with the object, perpendicular to the mirror.*

There are two kinds of images, *real* and *virtual.*

A real image is an image through which the rays of light actually pass.

A virtual image is an image through which the rays of light apparently pass, but do not.

It will be seen by these definitions that the image in a plane mirror is virtual. Why?

118. Concave Mirrors. — *A concave mirror is a mirror which curves, and has the hollow side towards the object.*

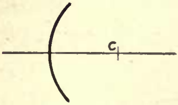

FIGURE 74. — A SPHERICAL MIRROR.

There are several kinds of concave mirrors. The two most common ones are the *spherical* mirror (Figure 74) and the *parabolical* mirror (Figure 75).

The spherical mirror is a portion of the surface of a sphere, every point of which is equidistant from one point (*c*) called the *center of curvature.*

The parabolical mirror is the portion of the surface of a paraboloid and is of the shape shown in Figure 75. The parabolical mirror is much better than the spherical because it gives a perfect image, while the other does not.

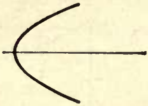

FIGURE 75. — A PARABOLICAL MIRROR.

119. Meaning of Terms. — In Figure 76 the point *c* is the *center of curvature,* and is equidistant from all points in the surface of a spherical mirror. The line *XO* is the *principal axis,* and is the line passing through the center of curvature (*c*) and the center of the mirror (*O*).

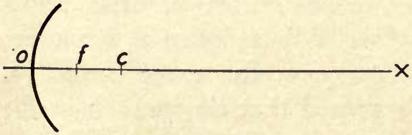

FIGURE 76. — THE PRINCIPAL POINTS OF A SPHERICAL MIRROR.

The *focus* of a mirror is the point at which the image is located. The point *f* is the *principal focus*, and is the point at which all rays parallel to the principal axis are focused. The principal focus is located at *one half the distance from c to O.* The *focal length* is the distance (*Of*) from the center of the mirror to the principal focus.

120. Image in a Concave Mirror. — Figure 77 shows the construction of an image in a concave mirror.

First, draw *ad* from *a*, the head of the object, parallel to the principal axis. Since this is a ray parallel to the principal axis, it must be reflected through the principal focus *f*. This determines line *dx*.

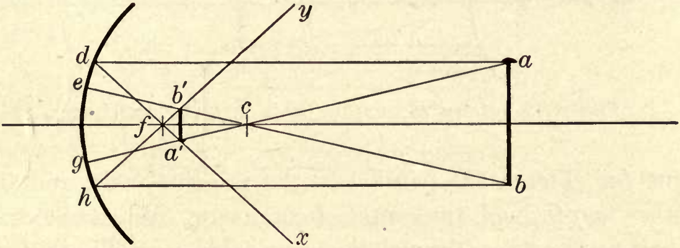

FIGURE 77. — CONSTRUCTION OF IMAGE IN A CONCAVE MIRROR.

Second, draw *ag* from *a* through the center of curvature *c*. This ray is reflected back upon itself, since it strikes the mirror perpendicularly. The point *a′*, where these two reflected rays meet, is the head of the image.

Third, locate the tail of the image in the same way. This completes the construction of the image.

This image is seen to be *real, inverted,* and *smaller than the object.* The image may be located by this method for any position of the object. The description of the image can then be easily given from the figure.

121. Convex Mirrors. — *A convex mirror is a curved mirror which has the hollow side of the curve away from the object.*

The same terms, *focus, axis, etc.,* apply to the convex mirror as to the concave mirror.

122. Image in a Convex Mirror. — The construction of the image in a convex mirror is the same as for the concave mirror. Draw the two lines from the head of the object, one (*ad,* Figure 78) parallel to the principal axis, and the other (*ac*) through the center of curvature. When reflected, these two rays pass through the principal focus and back upon themselves, respectively. Where they meet (*a′*) is the image of the head. The image of the tail (*b′*) is located in a similar manner.

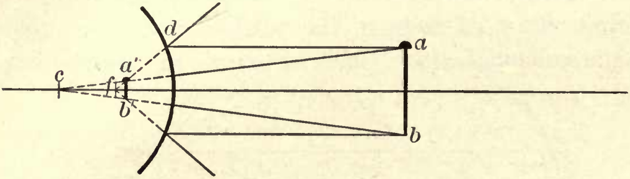

FIGURE 78. — CONSTRUCTION OF IMAGE IN A CONVEX MIRROR.

In this case the image is *virtual, erect,* and *smaller than the object.*

123. Applications of Mirrors. — 1. *Plane Mirror.* The general use of the plane mirror as a looking glass is too familiar to need discussion.

2. *Concave Mirror.* The most general use of the concave mirror is that of a reflector. Since all parallel rays come together at the principal focus, it is seen that the rays from a source of light placed at the principal focus will be sent out as parallel rays. (Figure 79.)

The automobile headlight is an example of this. The bulb is so placed that the filament of the lamp is very near the principal focus of the reflector. This sends the rays out in nearly parallel beams. The correct position of the filament is just beyond the principal focus, but *close* to it. This makes the rays cross and then diverge slightly, so that a large area of the road can be seen. The same use is also made in many different kinds of lamps.

The concave mirror is used in all telescopes of the reflector type. The largest telescope of this sort has just been completed by the Warner Swazey Company, of Cleveland, to be used at the Canadian observatory at Victoria.

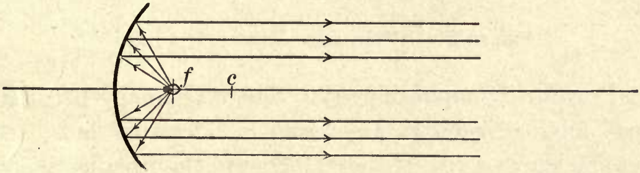

FIGURE 79.—A CONCAVE MIRROR USED AS A REFLECTOR.

The concave mirror for this telescope is 72 inches in diameter, and, like all high-grade concave mirrors, is of the parabolical shape. The telescope will be used to take photographs of distant stars. The mirror is large so that many rays of the star are focused at the image.

3. *Convex Mirror.* The convex mirror is often used on automobiles to give the driver a view of vehicles behind him. It is usually placed on the front fender or attached to the side of the windshield. The mirror gives a small but clear image of everything in the rear.

Large spheres with mirror surfaces are often placed in flower gardens to add to the decorations and to give beautiful images of the walks and flowerbeds.

Another use of the convex mirror is that of the " vanity-mirror " carried in ladies' hand bags or pocketbooks. It is much preferred to the plane mirror, for even a small one an inch in diameter will give an image of the whole face.

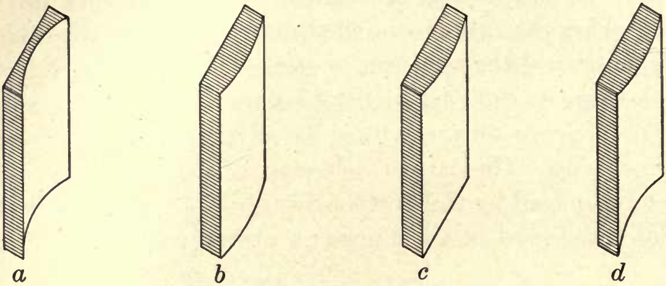

FIGURE 80. — PECULIARLY SHAPED MIRRORS.

4. *Peculiarly Shaped Mirrors.* There are many peculiarly shaped mirrors, such as are found in " hilarity halls," etc. Figure 80 shows a few of these. Due to the peculiar shapes, the images are distorted and afford amusement for the patrons.

CHAPTER X

REFRACTION AND LENSES

124. Refraction. — The term *refraction* is very often confused with the term *reflection,* but it must be borne in mind that the two mean entirely different things.

Refraction is caused by the change in velocity of a ray of light when it passes from one medium to another. This causes a bending of the ray when it strikes at an angle other than 90°.

If a lead pencil be put into a beaker of water (Figure 81), it looks as if the lead pencil were bent at the water line. If you try to touch an object under water very quickly, your hand will pass over the object, showing that the object appears higher than it really is. If you look through a poor grade of window glass at some straight line, such as the side of a tall chimney, the line looks jagged and crooked. (Figure 82.)

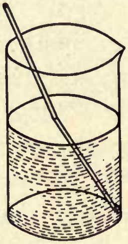

FIGURE 81. — A PENCIL LOOKS BENT AT THE SURFACE OF THE WATER.

All these illusions are caused by refraction.

125. Refraction Explained. — Figure 83 shows a ray of light (*A*) passing from air, through a piece of plate glass, back into air.

The small lines *ab* represent the wave front of the ray. A ray of light always travels at right angles to its wave front; so the wave front determines its direction.

The ray travels in a straight line until it strikes the glass. The side *a* strikes first, and so is retarded, since light cannot travel in glass as fast as in air. This allows *b* to swing ahead, since it is still in air. This continues until both *a* and *b* are inside the glass. Then they again go at equal speeds, giving the ray a straight path, but one slightly deviated from its original path.

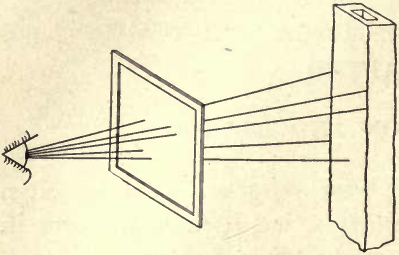

FIGURE 82. — A CHIMNEY VIEWED THROUGH POOR WINDOW GLASS.

At the other side of the glass, *a* comes to the surface first, and so swings ahead of *b*, for it now travels in air. It continues to do this until both *a* and *b* are again in air. Here they continue again at equal speeds, and the ray again goes in a straight line.

If the two sides of the glass are parallel, the ray swings back just as much as it deviated in the first place. This makes its path parallel to its path before entering the glass, but not in the same line.

If the two sides of the glass are not parallel, the ray will not be parallel with its first path, but will deviate according to the angle of the two surfaces.

126. Meaning of Terms and Law of Refraction. — In refraction, the *incident ray* is the ray before it strikes the refracting surface (AO for the first surface, and OO' for the second surface, Figure 83).

The refracted ray is the ray after it strikes the refracting surface (OO' for the first surface, and $O'A'$ for the second surface).

The *angle of incidence* is the angle between the incident ray and the perpendicular to the surface (angle i for the first surface, and angle i' for the second surface).

The *angle of refraction* is the angle between the refracted ray and the perpendicular to the surface (angle r for the first surface, and angle r' for the second surface).

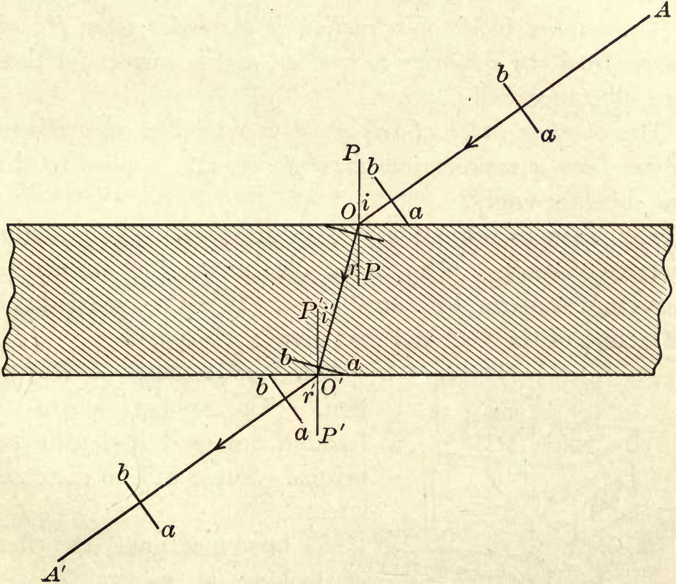

Figure 83. — Diagram Explaining Refraction of Light.

The law of refraction: *A ray of light passing from a rare medium into a denser medium always bends toward the perpendicular, and a ray of light passing from a dense to a rarer medium always bends away from the perpendicular.*

127. Index of Refraction. — Different substances refract light in varying degrees. In order to compare and express these amounts of refraction a term called *index of refraction* is used.

The index of refraction is equal to the velocity in the rare medium divided by the velocity in the dense medium.

$$\text{Index of Refraction} = \frac{V_{\text{rare}}}{V_{\text{dense}}}$$

There are two kinds of indexes of refraction, *relative* and *absolute.*

The *relative index of refraction is the index when the ray passes from one substance to another,* and is correct for those two substances only.

The *absolute index of refraction is the index when the ray passes from a vacuum into a substance,* and applies to that one substance only.

The index of refraction is used principally in the manufacture of lenses. The index determines the amount of curvature that the lens must have. It is the high index of refraction of the diamond that gives it its sparkle.

128. Applications of Refraction. — The applications of refraction are used in lenses and prisms. These will be discussed later.

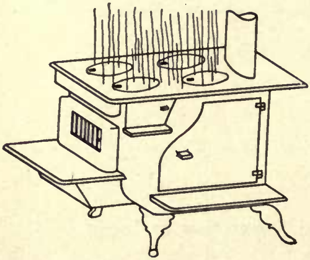

FIGURE 84.—REFRACTION OF LIGHT ABOVE A HOT STOVE.

We have mentioned the effect of looking at a straight line through a poor grade of window glass. Explain this.

It is a common thing to notice the wavy effect above a fire or stove (Figure 84). This is not heat waves, as so many think; but it is due to refraction. The air above the fire is heated and becomes less dense than the surrounding air. Light rays passing through these layers of air of unequal densities are refracted, giving the wavy effect.

Our atmosphere acts as a refracting substance to the sun's rays. For this reason we can actually see the sun before it is above the horizon in the morning, and also after it has gone below the horizon in the evening. (Figure 85.)

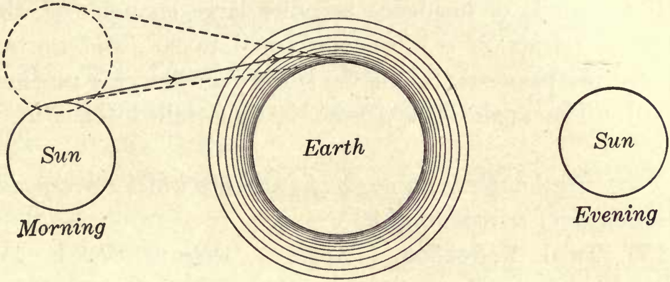

FIGURE 85. — REFRACTION OF LIGHT BY THE EARTH'S ATMOSPHERE.

129. Critical Angle. — Figure 86 shows what takes place when a ray of light passes from a dense medium, such as water, to a rare medium, such as air.

A ray of light AO passes from the dense medium and goes into the rare medium at O. According to the law of refraction, the ray is bent *away* from the perpendicular PP', making the angle of refraction r *larger* than the angle of incidence i. (Figure 86.)

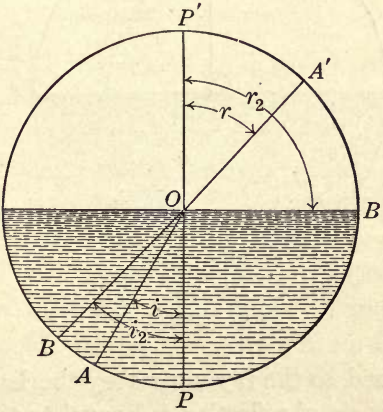

FIGURE 86. — DIAGRAM EXPLAINING CRITICAL ANGLE.

Now, if the angle of incidence is made larger and larger, the angle of refraction will become larger and larger also and will always be greater than its corresponding angle of incidence.

If the angle of incidence becomes large enough (i_2), the angle of refraction (r_2) becomes equal to 90°, and the refracted ray passes out along the surface of the dense medium (OB'). The angle of incidence is then called the *critical angle.*

The critical angle is an angle of incidence which corresponds to an angle of refraction of 90°.

130. Total Reflection. — Angle i (Figure 87) is the critical angle, and so the refracted ray OA' passes out along the surface of the dense medium, making the angle of refraction (r) equal to 90°.

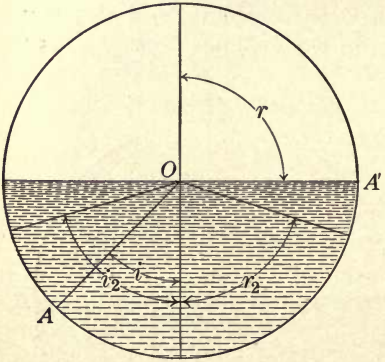

FIGURE 87. — DIAGRAM EXPLAINING TOTAL REFLECTION.

Now, if the angle of incidence is made still larger, such as i_2, the angle of refraction becomes greater than 90°. This makes the refracted ray return into the *same* medium in which it entered. But this is *reflection* instead of *refraction,* and so the ray must obey the law of reflection, making the angle of reflection (r_2) equal to the angle of incidence (i_2).

This is called *total reflection,* because none of the rays can be refracted, but *all* are reflected.

Total reflection is reflection against a surface of a rare medium when the angle of incidence is greater than the critical angle.

It must be noted that total reflection takes place only when the ray is passing from a dense to a rare medium.

APPLICATIONS OF TOTAL REFLECTION

131. The Lighthouse Reflector. — The lighthouse reflector is an application of total reflection. The source of light, a gas flame or an electric light bulb, is placed at the center. (*L*, Figure 88.) Circular right-angled prisms (Figure 89) are placed around the light at *P*, *P*, *P*, etc. (Figure 88), forming an inclosed sphere. Instead of the prisms being far apart, as in the figure, they are placed so close together that no light gets out between them.

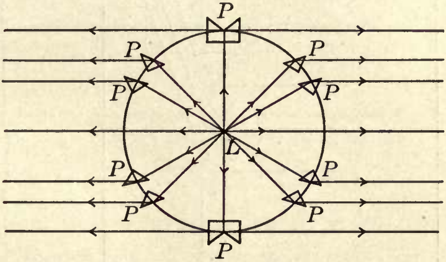

FIGURE 88. — POSITIONS OF PRISMS IN A LIGHTHOUSE REFLECTOR.

FIGURE 89. — A LIGHTHOUSE REFLECTOR PRISM.

The light coming from the center strikes one leg of the right-angled prism, enters the glass, and then strikes the hypotenuse at an angle greater than the critical angle. Total reflection takes place, and all the light is sent out in a parallel beam. By this means all the light is utilized, top, bottom, and sides.

132. Prismatic Window Glass. — Very often it is impossible by means of the ordinary windows to get sunlight into rooms shaded by other buildings, especially in large cities where " skyscrapers " are the rule. Prismatic window glass helps to do away with this difficulty. The light coming almost straight down (Figure 90) strikes the prismatic glass and is totally reflected into the room.

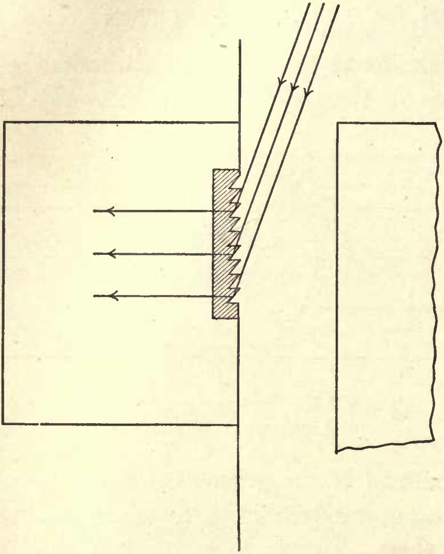

FIGURE 90. — USE OF PRISMATIC WINDOW GLASS.

133. Field Binoculars. — In the field binoculars, such as are used by officers of the army and navy, the light must pass a distance of several inches after it enters the instrument before it reaches the eye. To keep the instrument from becoming too long, the rays of light are reflected back and forth from one end to the other by means of right-angled prisms.

Figure 91 shows a diagram of the path of a light ray in one tube of the binocular.

134. A Fish's View of the Outside World. — It is rather interesting to note just how the outside world looks to the fish below the surface of the water. Figure 92 is a diagram showing how the rays of light come to the fish's eye.

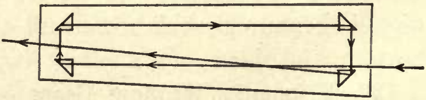

FIGURE 91. — TOTAL REFLECTION USED IN THE BINOCULARS.

The sky and all objects above the horizon are seen through a cone whose angle is about 97°. Outside of this cone the fish gets rays coming from the bottom and reflected at the surface of the water. This makes the sky look as if it had a fringe of stones or grass, according to whether the bottom is stony or grassy.

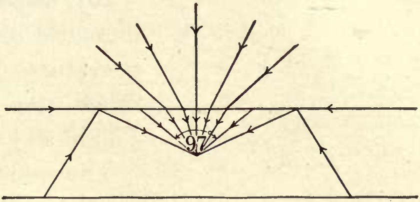

FIGURE 92. — A FISH'S VIEW OF THE OUTSIDE WORLD.

135. The Diamond. — As mentioned before, the large index of refraction in a diamond gives it its sparkle. As the diamond has a large index of refraction and is cut with many facets, the light is reflected many times within the stone, so that there is scarcely an angle at which you can view it without getting a flash of light.

LENSES

136. Lenses. — A lens is a transparent body of such a shape that it will *focus* rays of light. There are two general classes of lenses: (*a*) *converging*, (*b*) *diverging*.

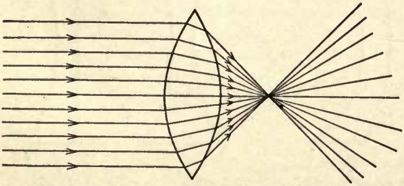

FIGURE 93. — LIGHT PASSING THROUGH A CONVERGING LENS.

A converging lens is a lens which tends to bring the rays together after they pass through. (Figure 93.)

A diverging lens is a lens which tends to send the rays farther apart after they go through. (Figure 94.)

Lenses are of different shapes and are given specific names according to these shapes. (Figure 95.) In general, lenses that are *thicker at the center* than at the edges are *converging,* while those *thinner at the center* than at the edges are *diverging.*

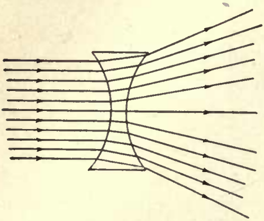

FIGURE 94. — LIGHT PASSING THROUGH A DIVERGING LENS.

137. Meaning of Terms. — The line drawn through the centers of curvature of the two surfaces is called the principal axis. (*CC,* Figure 96.)

The *optical center* (*O*) is the point on the principal axis, midway between the surfaces of the lens.

The *principal focus* (*F*) is the point at which all rays parallel to the principal axis are focused.

The *focal length* (*OF*) is the distance from the optical center to the principal focus.

The *image* is a point, or a series of points, at which the rays coming from an object are focused. The rays coming from *one point* of the object are focused at *one point* in the image.

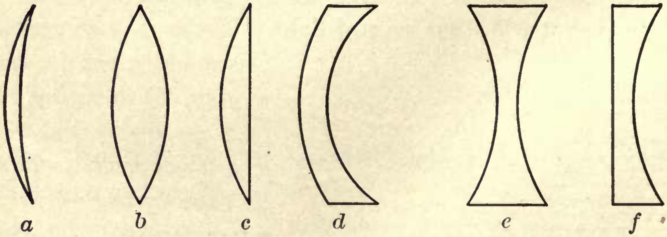

FIGURE 95. — DIFFERENT SHAPED LENSES.

138. Image through a Converging Lens. — There are five possible settings for a converging lens:

I. *The object beyond 2 F.*

To construct the image for this position (Figure 97) draw the lens and the principal axis; locate the optical center and the principal focus. (*Note:* Every lens has its own focal length; and if this is given, the principal focus can be located by it; but if the focal length is not given, then a focal length must be assumed.) Next, mark off *F* and 2 *F* on both sides of the lens, and place the object beyond 2 *F*.

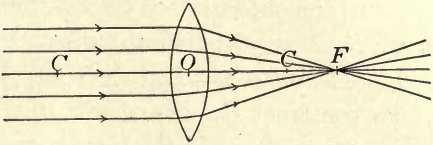

FIGURE 96.—PRINCIPAL POINTS OF A LENS.

Now, there are an infinite number of rays passing from every point of the object, but two rays are sufficient to locate the image of any one point. Select the two rays, one of which is parallel to the principal axis, and the other which passes through the optical center.

To locate the head of the image draw these two rays, the one parallel to the axis passes through the principal focus *F* (because all parallel rays are focused at this point), and the one through the optical center passes on through the lens in a straight line (it really zigzags just a little at the lens). The point at which these two rays meet is the image of the head.

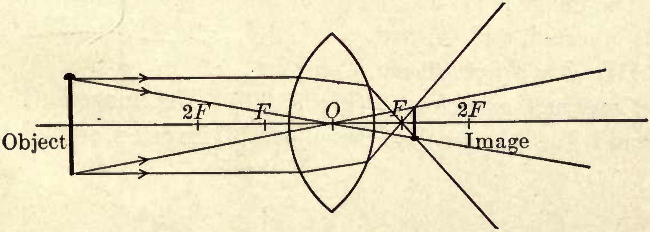

FIGURE 97.—CONSTRUCTION OF IMAGE WHEN OBJECT IS BEYOND 2 F.

In the same way the tail of the image is located, thus locating the whole image.

The description of an image gives four things: (1) position, (2) size, (3) whether it is erect or inverted, (4) whether it is real or virtual.

When the object is beyond 2 *F*, the image is (1) between *F* and 2 *F*, (2) smaller than the object, (3) inverted, and (4) real.

II. *The object at* 2 *F*.

To construct the image with the object in this position, proceed exactly as in the former case. (Figure 98.)

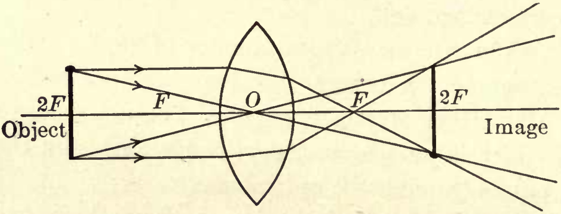

FIGURE 98. — CONSTRUCTION OF IMAGE WHEN OBJECT IS AT 2 *F*.

The image is (1) at 2 *F*, (2) of the same size as the object, (3) inverted, and (4) real.

III. *The object between F and 2 F*.

Construct as before. (Figure 99.) The image is (1) beyond 2 *F*, (2) larger than the object, (3) inverted, and (4) real.

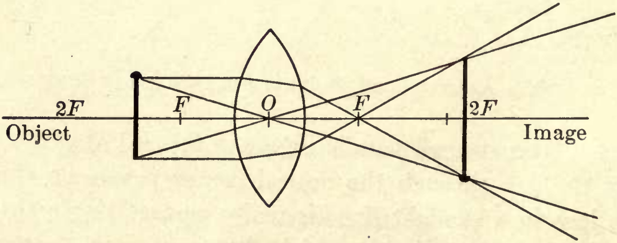

FIGURE 99. — CONSTRUCTION OF IMAGE WHEN OBJECT IS BETWEEN *F* AND 2 *F*.

IV. *The object at F.*

Construct as before. (Figure 100.) The rays after passing through the lens are parallel, and so never meet. Therefore there is *no image.*

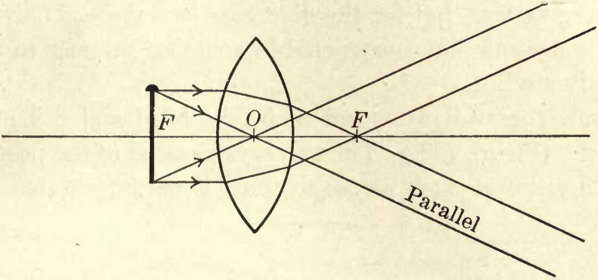

FIGURE 100.—CONSTRUCTION OF IMAGE WHEN OBJECT IS AT *F*.

V. *The object between F and the lens.*

The construction is the same as before, except that the rays after passing through the mirror diverge, and so have

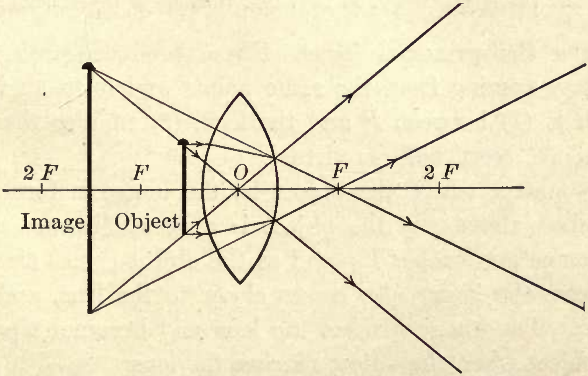

FIGURE 101.—CONSTRUCTION OF IMAGE WHEN OBJECT IS BETWEEN *F* AND THE LENS.

to be produced *backward* to determine the point where they meet. (Figure 101.)

The image, then, is (1) on the same side of the lens as the object, (2) larger than the object, (3) erect, and (4) virtual.

139. Image through a Diverging Lens. — There were five distinctive positions for the object in the case of the converging lens, but for the diverging lens there is only one. The image may be constructed in a similar manner to those already studied.

Draw the two rays from each, the head and tail of the object. (Figure 102.) The two rays parallel to the principal axis diverge at such an angle that, if produced, they pass through the principal focus. These produced rays meet the rays coming from the same points and form an image which is (1) between *F* and the lens, (2) smaller than the object, (3) erect, and (4) virtual.

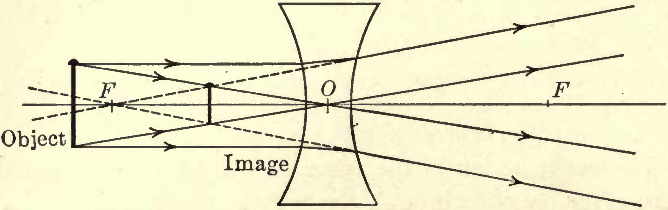

FIGURE 102. — CONSTRUCTION OF IMAGE THROUGH A DIVERGING LENS.

No matter where the object is, the image is formed as described above. If the object is a great distance away, the image approaches *F*; and as the object comes closer to the lens, the image also comes closer to the lens, and gets larger. The image reaches the lens and becomes equal to the object when the object reaches the lens.

APPLICATIONS OF LENSES

140. The Pinhole Camera. — The simplest camera that we have is illustrated by Figure 103. It consists of a light-tight box with a pinhole in the front. A sensitized plate or film may be placed at the back, and a picture can be taken. The principle of the pinhole camera is this: All the rays allowed to pass through the pinhole from the same point of the object fall at the same point at the back of the box. A series of these points forms the image.

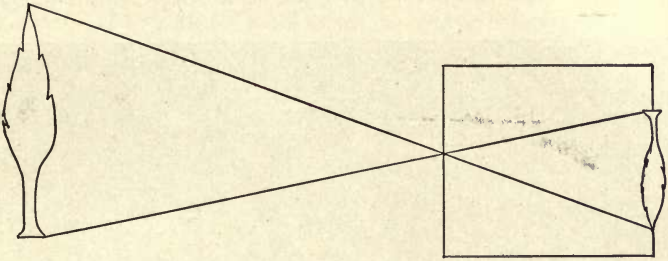

FIGURE 103. — THE PINHOLE CAMERA.

141. The Lens Camera. — The pinhole camera is not satisfactory, for if the pinhole is very small, the image will be very weak and dim; and, on the other hand, if the hole is made large, then the rays from the same point on the object fall over quite an area of the image, and this makes the image indistinct, or blurred.

FIGURE 104. — THE LENS CAMERA.

By the use of a converging lens, Fig. 104, the opening may be made large and, at the same time, the image may be kept sharp and distinct. This is an application of the converging lens with the object beyond 2 *F*.

In order that *all* the rays coming through the lens from one point of the object be focused at a single point of the

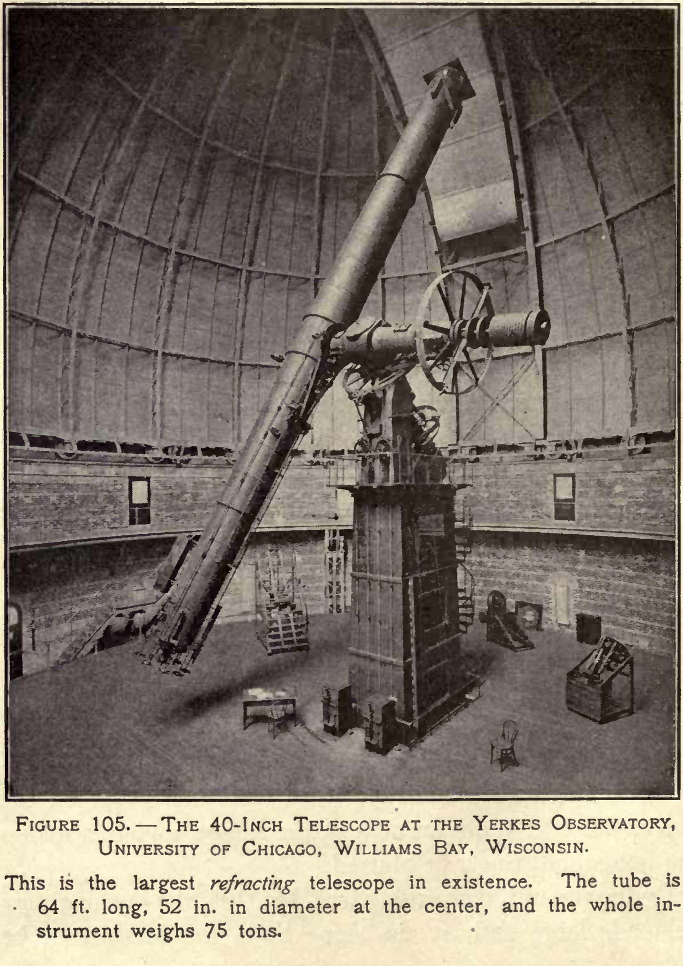

FIGURE 105. — THE 40-INCH TELESCOPE AT THE YERKES OBSERVATORY, UNIVERSITY OF CHICAGO, WILLIAMS BAY, WISCONSIN.

This is the largest *refracting* telescope in existence. The tube is 64 ft. long, 52 in. in diameter at the center, and the whole instrument weighs 75 tons.

image, the lens must be ground with great care. This is why the best cameras are so expensive.

The plate or film upon which the picture is taken is a piece of glass or other transparent substance covered with a gelatin. This gelatin is of such a composition that when sun light strikes it, it is made *insoluble.* When a picture is taken, the rays from the light parts of the object affect the plate more than the rays from the dark parts. Then, when the plate is " washed " the unaffected parts dissolve, leaving the insoluble part on the plate.

The plate is then washed in a " fixing " solution, which makes the remaining gelatin hard to scratch. The plate is now called the *negative.* It has *dark* spots where the object is *light,* and *light* spots where the object is *dark.*

For printing the pictures, either a paper or glass with a sensitive gelatin is used. The " negative " is laid over the sensitive paper or glass and held in the sun for a short time. The sensitive plate is affected just as the negative was when it was made, except that the dark and light spots are reversed, thus reproducing the object as it was seen.

As all these processes must be done with painstaking care, photography is quite an art.

142. The Eye. — The eye is also an application of the converging lens when the object is placed beyond 2 F.

The human eye is about an inch in diameter and has three coats. The outer coat is very thick and strong, and is called the *sclerotic coat.* (Figure 106.) This sclerotic coat covers the entire eyeball, but at the front it is transparent and this portion has the name *cornea* (C).

The next coat (D) is dark in color, and is called the *choroid coat.* At the front, the choroid coat forms a kind of curtain, called the *iris* (I). The iris is the part that gives color to the eye. At the back of the eye is a third coat (R) called the *retina.* This is nervous tissue composed of millions of small nerve cells. These cells are divided into three classes. In one class are those affected by *red* light; in another class are those affected by *green* light; and the third class is composed of those affected by *blue* light. These different kinds of cells are not in separate groups, but are scattered all over the retina, so that every point has all three kinds.

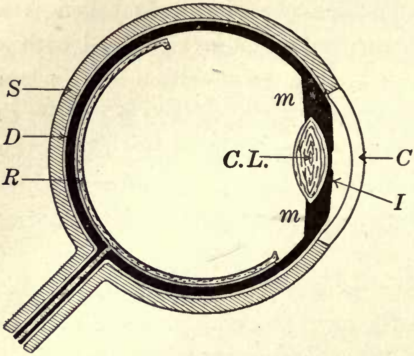

FIGURE 106.—THE EYE.

At the front of the eye, fastened into the choroid coat, are muscles (m, m).

These muscles are so attached that they stretch or relax a small membrane sack which contains the *crystalline* lens ($C. L.$). This crystalline lens is a transparent, jelly-like mass, and is a true lens.

143. How We See. — When an object is held before the eye, an image is focused by the crystalline lens upon the retina. The nerve cells are affected according to the color of the light which falls on them. Impulses are sent to the brain, and we become conscious of the image.

A further study of color will be taken up later, and the subject of the eye should then be reviewed.

144. Defective Eyes. — There are many defects of the eye, but we will mention only three: *short-sightedness* (*myopia*), *long-sightedness* (*hypermetropia*), and *astigmatism.*

Short-sightedness is caused by one, or both, of two things. The eyeball is too long, or the crystalline lens is too thick. When the image falls in *front* of the retina, the person has to bring the object very near the eye to get the image to move back upon the retina. (Figure 107.)

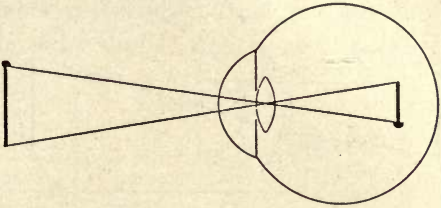

FIGURE 107. — A SHORT-SIGHTED EYE.

To correct this defect, diverging lenses should be used for eye-glasses. This makes the image fall upon the retina when the object is held at the natural position. (Figure 108.)

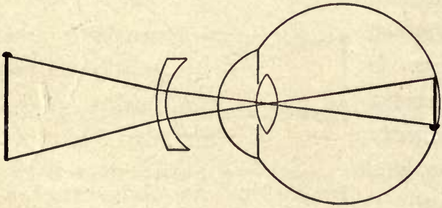

FIGURE 108. — A SHORT-SIGHTED EYE CORRECTED.

Long-sightedness is just the opposite of short-sightedness, and is caused by just the opposite things. The eyeball is too short, or the lens is too thin. This makes the image fall back of the retina, so that it is necessary to hold the object far away in order to get the image to fall on the retina. (Figure 109.)

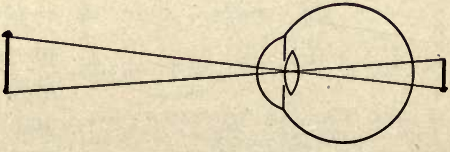

FIGURE 109. — A LONG-SIGHTED EYE.

Glasses to correct this defect should be converging lenses. (Figure 110.)

Astigmatism is the most serious of the three defects, and is much the hardest to correct. It may be caused by several things, such as irregularities in the thickness or texture of the cornea, or in the crystalline lens.

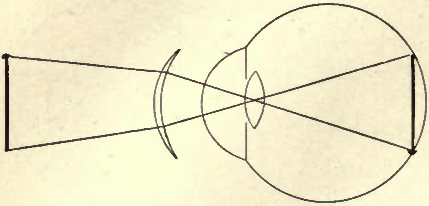

FIGURE 110. — A LONG-SIGHTED EYE CORRECTED.

Figure 111 shows an eye with irregular thickness of the cornea. The defect must be corrected by having glasses ground to fit this one special case, and this requires an expert. Figure 112 shows an attempt to correct astigmatism.

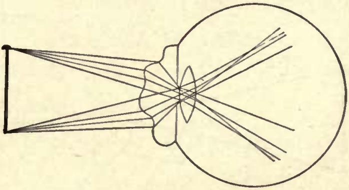

FIGURE 111. — AN ASTIGMATIZED EYE.

145. The Life-size Picture Camera. — This camera is just like the ordinary camera except that the box is very long and large and the lens has a greater focal length.

This is an application of the second position of the converging lens. The object is placed at 2 *F* in front, and the plate is placed at 2 *F*, back of the lens in the box. (Figure 113.)

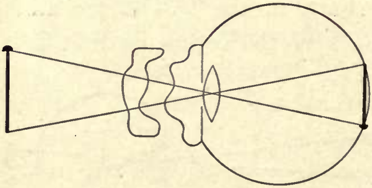

FIGURE 112. — AN ASTIGMATIZED EYE CORRECTED.

It is used for taking photographs of machinery and parts of machinery, and sometimes of persons.

146. The Projection Lantern. — The projection lantern (Figure 114) is an application of the converging lens with the object placed between *F* and 2 *F*.

An arc light is used to illuminate the object (*O*, Figure 114), which is usually a picture on a glass plate called a *slide*. In order that more of the light from the arc may strike the object, and in order that it may come in parallel rays, *condensing lenses* (*c*, *c*) are placed between the arc and the object.

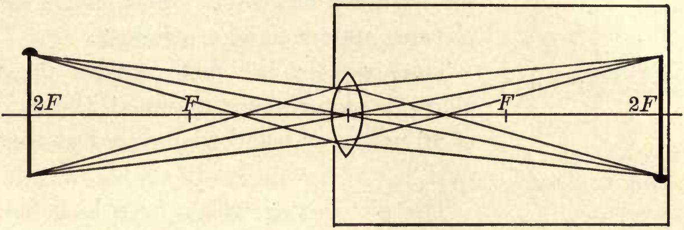

FIGURE 113. — A LIFE-SIZE PICTURE CAMERA.

Now, the slide or object is placed between *F* and 2 *F* between the light and the lens, and the image is thrown on a screen some distance in front, the image appearing very large and inverted. To make the image erect, the slide is placed in the machine upside down.

FIGURE 114. — A PROJECTION LANTERN.

147. The Motion-picture Machine. — The motion-picture machine is merely a projection lantern with an attachment for changing the slides at the rate of 16 or more per second.

When images fall on the retina of the eye their effects tend to *linger* ; that is, after the image has left the retina the nerves do not lose the effect immediately, and we continue to see the image for about $\frac{1}{16}$ of a second after it is gone.

Now, by throwing pictures upon a screen at the rate of 16 per second the last picture has not left our mind before the next one has come. This makes the pictures appear to be continuous.

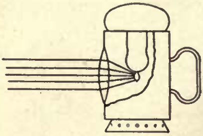

FIGURE 115. — A DARK LANTERN.

Thus we see the motion that takes place if pictures are taken at the rate of 16 per second and reproduced at that rate.

The pictures are taken on a long film and are about $\frac{3}{4}'' \times 1''$ in size. This film is run off a reel, through the motion-picture machine, on to another reel.

148. The Dark Lantern. — A good example of the converging lens with the object at *F* is the dark lantern. (Figure 115.)

Here the light is placed at the principal focus, and after passing through the lens it goes in a parallel beam.

149. The Magnifying Glass. — Figure 116 shows a converging lens used as a magnifying glass. The lens is held at a

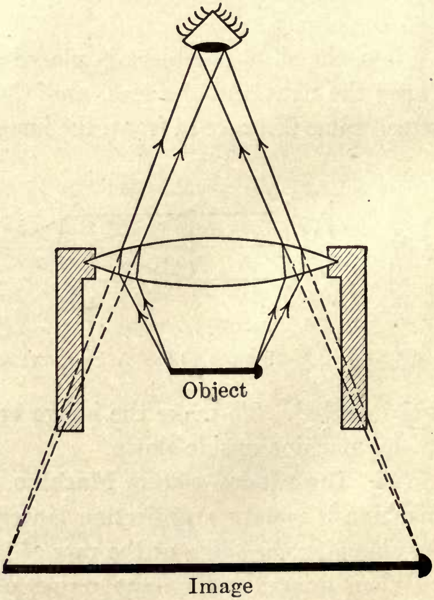

FIGURE 116. — A POCKET MAGNIFYING GLASS.

distance less than F, and a large, erect, virtual image is obtained.

The magnifying glass is often used as a reading-glass. It is also used by biologists for examining plants and small insects.

150. Diffused Light. — Figure 117 (*b*) shows a beam of light falling on an irregular surface. Part of the light is absorbed, but the rest is reflected according to the law of reflection, making the angle of reflection equal to the angle of incidence.

Since the surface is irregular, the light is reflected in every direction. These reflected rays are called *diffused light*.

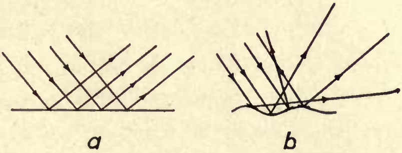

FIGURE 117. — EXPLAINING DIFFUSED LIGHT.

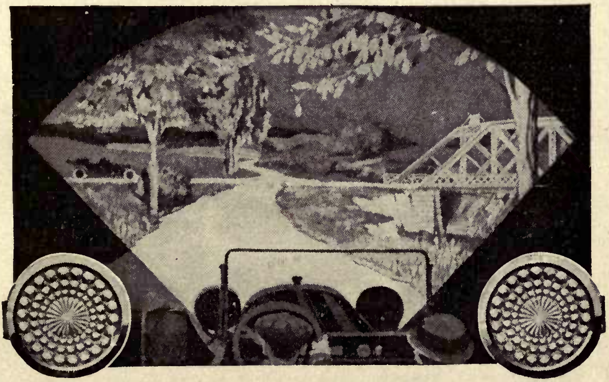

FIGURE 118. — THE AUTOMOBILE HEAD-LIGHT LENS DIFFUSES THE LIGHT.

It is by diffused light that we see all bodies which are not incandescent, that is, *light giving*. An object such as a perfect mirror (*a*, Figure 117), which reflects the light in parallel rays, cannot be seen. This is illustrated by the fact that a person will sometimes walk into a mirror and not know it until he has struck it. One looking into the mirror does not see the mirror, but only the objects reflected in it.

CHAPTER XI

ILLUMINATION AND CANDLE POWER

151. Intensity of Illumination. — One often desires to speak of the amount of light falling on a surface. To express this, the term *intensity of illumination* is used.

The intensity of illumination is the light energy per unit area.

To illustrate this definition, suppose you had a slice of bread and were to spread a serving of butter upon it. The butter would be of a certain thickness. Now, if an equal serving of butter were spread on several slices, its thickness would be much less. This is true of light.

When a certain amount of light falls on a definite area the intensity of illumination is a certain amount; but if the same light were spread over a larger area, the intensity would be less.

Every one has noticed that the greater the distance from the source of light, the weaker the light becomes. This is stated in the following law:

The intensity of illumination is inversely proportional to the square of the distance from the source of light.

To prove this law, suppose a cardboard (*a*, Figure 119) is placed before a light (*L*), the cardboard having a small hole in it. A second cardboard (*b*) with a square hole, one inch on a side, cut in it is placed *one foot* from *a*. A third cardboard (*c*) is placed *two feet* from *a*.

Now, the light coming through the square hole in *b* falls on a certain area on *c*.

From the figure it will be seen that the side of the illuminated square on *c* is *twice* the side of the square in *b*.

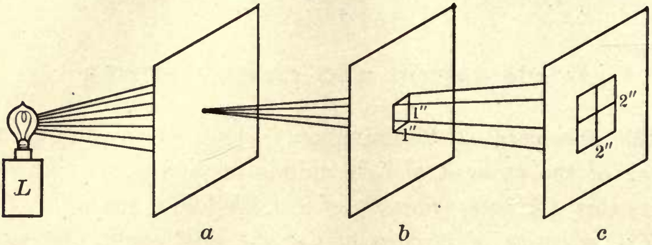

FIGURE 119. — EXPLAINING LAW OF INTENSITY OF ILLUMINATION AS THE DISTANCE VARIES.

Thus the light falls on an area at *c*, which is *four times* as large as on *b*; etc.

Thus *the area on which the light falls is directly proportional to the square of the distance from the source.*

Since the intensity of illumination is inversely proportional to the area, it is inversely proportional to the square of the distance from the object under consideration to the source of light.

This law can be applied to reading. If your book is three feet from the lamp the printed pages will be illuminated four times as strongly as if it were six feet away; nine times as strongly as if it were nine feet away; and 10,000 times as strongly as if it were 300 feet away. This shows you why it is so important to get close to the light to get proper illumination.

152. Candle Power. — We have discussed the intensity of illumination of objects lighted by some source other than themselves; but it is often desired to express the brightness of the source of light itself. The unit used for this is called the *candle power.*

One candle power is the light given by a standard candle burning under specified conditions.

The standard candle is made of sperm oil, weighs $\frac{1}{6}$ of a pound, is usually wrapped in tinfoil, and burns at the rate of 120 grains per hour.

It will be seen immediately that the unit *candle power* is, at best, a poor unit, because no matter how much care is taken to get the conditions the same, a candle will never give exactly the same light. It is like using a tape measure made of rubber. Nevertheless, this unit is still used for want of a better one.

153. Measurement of Candle Power. — In measuring the candle power of a source of light, the light is compared to either a standard candle or to another light of which the candle power is known. To make this comparison the *photometer* is used.

The photometer is a piece of paper with a grease spot on it. This paper may be either placed in a small black box (Figure 120), or may be put in a standard which holds it in position.

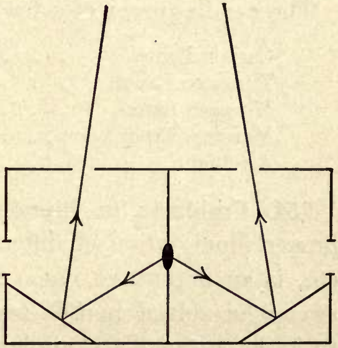

FIGURE 120. — CROSS SECTION OF BUNSEN PHOTOMETER.

To compare two lights, the photometer is held between them, at such positions that the illuminations on both sides of the paper are the same. (Figure 121.)

This point can be determined, since the grease spot will disappear, or look the same shade on both sides, when the correct position is reached.

By measuring the distance (d_x) of the unknown light (X) to the photometer, and the distance (d_s) from the known standard (S) to the photometer, the candle power of X can be calculated.

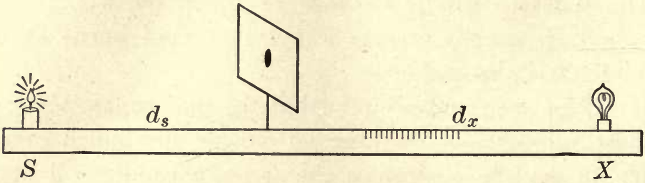

FIGURE 121. — COMPARING TWO LIGHTS BY USE OF PHOTOMETER.

$$X = \left(\frac{d_x}{d_s}\right)^2 \cdot S$$

The candle power of a few sources of light are as follows:

Carbon Lamp	about $\frac{2}{7}$ c. p. per watt
Tungsten Lamp	about $\frac{4}{5}$ c. p. per watt
Nitrogen Lamp	about 1 c. p. per watt
Mercury Vapor Lamp	about 1 c. p. per watt
Arc Light	about 1 c. p. per watt

154. Problems in Illumination. — The problem of the proper illumination of different kinds of buildings, streets, etc. is an important one. It is one which cannot be answered or solved in this text. Only a few suggestions as to its importance and application can be made.

In the home, care should be taken to have lights placed in the proper positions. Also, candle power of lamps to be used is largely determined by the decorations of the room.

For the kitchen, two lamps are usually needed: one above the sink, and one above the stove. Forty-watt tungsten lamps are, as a rule, a good rating.

A bedroom should have at least a 40-watt tungsten. This should be hung above the dresser or dressing table, and not from the center of the ceiling.

The bathroom should have two lamps, one on each side of the mirror. Twenty-five-watt tungstens are sufficient.

The lamps in the living rooms, library, etc., cannot be specified, but should be placed so as to be most convenient and at the same time bring out the desired effects of the decorations.

It is astonishing what different effects may be obtained by different lightings of the same piece of statuary. The same is true of paintings.

CHAPTER XII

COLOR

155. Dispersion. — If a ray of white light be passed through a glass prism (Figure 122), it will be refracted and at the same time will be broken up into a band of seven colors, in the order of *violet, indigo, blue, green, yellow, orange,* and *red* (*vibgyor* contains the initials of the colors in the regular order). This breaking up of white light is called *dispersion,* and the band of seven colors is called the *solar spectrum.*

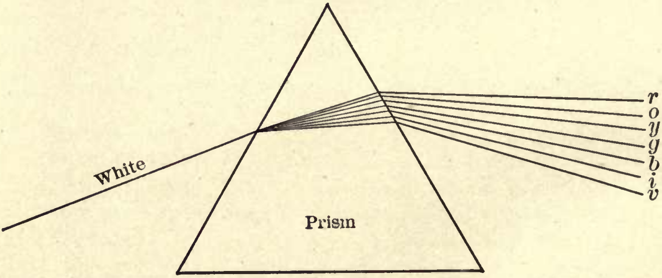

FIGURE 122. — WHITE LIGHT PASSING THROUGH A PRISM.

156. Cause of Different Colors. — At the beginning of our discussion of light we said that light is a wave motion in the ether. Different wave lengths give differently colored light; that is, the color of the light depends upon the wave length, just as the high tones in sound have different wave lengths from the low tones.

The violet rays are the shortest waves (about .000033 cm.) which the eye can see, while the red rays are the longest (about .000081 cm.), the other colors falling in between, in the given order.

When a piece of iron is heated, it first becomes *red hot* and later *white hot.* As more heat is applied, the molecules vibrate faster and faster, sending out shorter and shorter wave lengths as well as the longer ones, thus producing all the colors of the spectrum. Just as white light can be broken up into all these colors, so they now combine and make the iron look *white.* Hence the term *white hot.*

This same thing can be noticed in the filament of an electric lamp when it is partially lighted, then fully lighted.

157. The Achromatic Lens. — When a lens is made of one piece of glass, it does not refract all colors equally; in other words, *dispersion* takes place. This makes it impossible to get a perfect focus with this kind of lens.

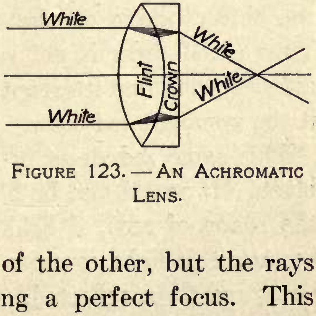

FIGURE 123. — AN ACHROMATIC LENS.

To correct this defect, lenses are made of crown and flint glass. (Figure 123.) The dispersive effect of one glass counteracts the dispersive effect of the other, but the rays are still refracted, thus producing a perfect focus. This kind of lens is called *achromatic* — without color. These lenses are very expensive and are used only in high-priced cameras, microscopes, and other optical instruments.

158. Transparent, Translucent, and Opaque Objects. — Objects are divided into three classes, according to their ability to transmit light.

Transparent objects are those which transmit light in parallel rays; and thus objects can be seen in detail through them.

Translucent objects are those which transmit light, but not in parallel rays, so that objects cannot be seen in detail through them. Light after coming through a translucent object is diffused.

Opaque objects are those which shut off the light entirely.

Air, clear plane glass, clear water, etc., are examples of transparent objects.

Snow, cracked ice, frosted glass, thin paper, etc., are examples of translucent objects.

Wood, iron, stone, etc., are examples of opaque objects.

159. Color of Opaque Objects. — No object, unless it is self-illuminated, has color. It gets its color from the light that falls on it.

The light that falls on it is either absorbed or reflected, the object taking on the color of the light that it reflects. Thus a red dress is not red at all, but merely absorbs all colors that fall on it except red, which it reflects, thus giving it the apparent red color.

This same red dress in a perfectly dark room would be black. It would also be black, or purplish (depending upon the shade of red), if held in the light of a sodium flame, because this light contains only yellow, and so there would be no red to be reflected.

160. Dyes. — A *dye* is a substance which may be made to stick between the fibers of another object and thus give the object an apparent color by reflecting that colored light.

Cloth is usually dyed by placing it in a liquid containing certain substances which enter the cloth and stick between the fibers after the dye has dried. If it is a good dye, it is of such a nature that these particles cannot be washed out, causing the cloth to fade. A good dye should also be unaffected by sunlight.

When a cloth fades, the small particles are either washed out or are so changed chemically that they will not reflect the desired color.

161. Paints. — Paints are different from dyes in that they are colored pigments which are spread over the surface of an object, instead of going in between the fibers. The color of the paint is determined by the colored light which the pigments reflect.

162. Color of Transparent and Translucent Objects. — Transparent and translucent objects get their color from the light which they *transmit.* A green glass is *green* because it absorbs all other colors and transmits the green. Objects viewed through green glass appear green because that is the only kind of light that gets through.

Colored glass is made either by putting the coloring material in the glass when it is manufactured, or else by covering the glass with a film of gelatin containing the coloring-matter.

163. Application of Colored Objects. — From the preceding topics it is seen that the color of an object depends upon two things: *the kind of light falling on it,* and *the color which it reflects or transmits.*

The knowledge of this fact is applicable in the selection of dress goods and in the illumination of pictures and other decorations.

In selecting dress goods, the selection should be made in the same kind of light as that in which the dress is to be worn. For example, if a piece of goods is selected in artificial light, it should be worn in the same kind of artificial light, for it may be of an entirely different color when viewed in daylight. As an exaggerated example, a bright red piece of cloth in daylight would appear dark purple or black in the light of a mercury vapor lamp. This is because there is no red light given off by the mercury lamp, and consequently the material has no red to reflect.

In the same way a blue piece of goods in daylight looks black under a carbon lamp, since the carbon lamp gives off very little blue light.

The same application can be made in illuminating pictures, wall paper, draperies, etc. These decorations will take on an entirely different color when placed under different colored lights.

A lamp has recently been put on the market, called the "day-light lamp." It is given this name because the rays sent out by it contain the same colors, and in the same proportion, as are found in sunlight. Most large stores now have these lamps, so that goods selected in this light will have the same color in sunlight.

164. The Three Primary Colors. — It was found that by passing white sunlight through a prism it could be dispersed into seven colors.

Each of these colors is *elementary ;* that is, it cannot be broken up into parts or other colors. This would lead us to believe that to get white light we must mix these seven colors, and this is partially true.

A mixture of these seven colors in the right proportions will give white light, but white light can also be obtained by the mixture of *three elementary colors : red, green, and violet.* More than that, *any color* whatsoever can be obtained by the correct proportions of these three colors.

For this reason the three colors *red, green,* and *violet* are called the *primary colors of light.*

165. How We See Color. — Referring back to the topic on "The Eye" (§ 142), it will be found that the retina, the inner lining of the back of the eye, is composed of countless numbers of nerve-endings or cells, that these cells are divided into three classes, but are all intermingled, so that even the smallest spot on the retina has all three kinds of cells.

One of these classes of cells is affected by *red light,* and *red only;* another is affected by *green light,* and *green only;* while the third class is affected by *violet light,* and *violet only.*

Now, when an image falls on the retina, these cells are affected by the light that strikes them. Where only *red light* falls, only those corresponding nerve cells are affected; the same for *green;* and the same for *violet.*

If a light such as *yellow,* which is composed of both *red* and *green,* falls on a spot on the retina, both those corresponding kinds of cells are affected.

When these cells are affected, impulses are sent to corresponding nerve cells in the brain, and we become conscious of those certain kinds of light falling on their respective positions on the retina. Thus we *know* the *shape* of the object and also its *color.*

166. Mixing Colored Lights. — It has been noted that lights of different colors may be mixed. When this is done, the result is the *combined* effects of all he lights each taken separately. This is called the *additive method.*

Thus, when the correct proportions of *red light* and *green light* are superimposed, the result is the sum of the *red* and *green* effects, which gives a *yellow.* Likewise, any color whatsoever may be produced by adding the proper portions of the three primary colors.

The above statements can be experimentally illustrated by the use of colored disks on a turning table. (Figure 124.) By placing these disks on the spindle, one over the other, in such a manner that a certain portion of each disk is visible, and then by turning the disks at a rapid rate, an apparent mixture of these colors is attained. The mixing is done on the same principle as the moving-picture (§ 147), each color effect being superimposed upon the retina of the eye before the other color effects disappear.

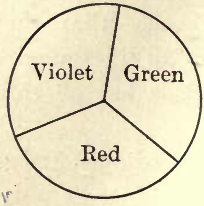

FIGURE 124. — COLORED DISKS.

167. Tints and Shades. — A *tint* of a certain color is produced by adding that color to *white.* In the same way *shades* of a color are produced by mixing that color with *black.*

168. Colored Pigments. — Colored pigments are used in paints and dyes, and are small particles of matter of such a nature that they reflect certain colors.

169. Mixing Pigments. — Mixing pigments to produce color is called the *subtractive method.* It is called subtractive because the color that is given out after mixing the pigments is that which is left after the pigments have absorbed their characteristic colors. Thus Figure 125 illustrates the adding of *red* and *yellow,*

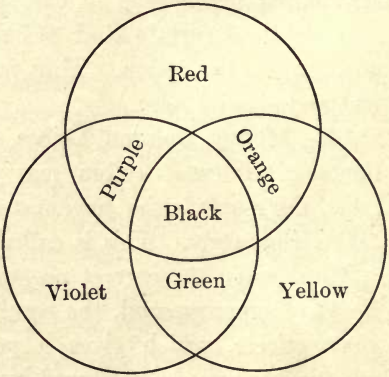

FIGURE 125. — ADDING RED, YELLOW, AND VIOLET LIGHTS.

yellow and *violet*, *violet* and *red*, and *red*, *yellow*, and *violet*. It will be seen that the resulting colors are, respectively, *orange*, *green*, *purple*, and *black*.

The three kinds of pigments, red, yellow, and violet, are called primary, because by adding them in the right proportion black is obtained.

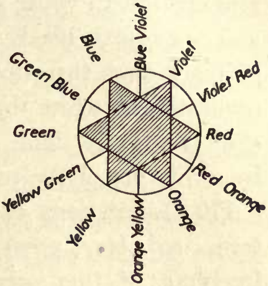

FIGURE 126. — MIXING SIX DIFFERENT COLORED PIGMENTS.

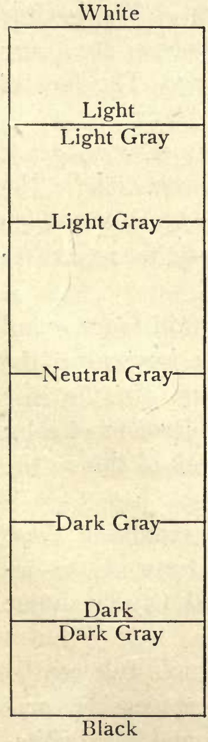

FIGURE 127. — DIFFERENT SHADES OF GRAY.

Each of the three kinds of pigments absorbs certain colors, giving back only its characteristic color. When the three kinds are mixed together, *no* color is given back, for what one gives back the others absorb. This produces the absence of color, or *black*.

Figure 126 is a diagram illustrating the mixing of six kinds of pigments, and the resulting effects. Thus a mixture of red and orange gives a *red-orange* ; a mixture of orange and yellow gives an *orange-yellow*, etc.

Opposite colors, such as *red* and *green*, *orange* and *blue*, *yellow* and *violet*, are called *complementary colors*, because if the one is taken from white the other is the result. For example, if *red* is taken from white, *green* is the result, etc.

Figure 127 is a diagram showing how

to obtain different shades of gray. Half white and half black give what is called *neutral gray*. Three-fourths black and one-fourth white give a *dark gray*. Three-fourths white and one-fourth black give a *light gray*. Greater quantities of black than three-fourths give a *dark dark-gray*. Greater quantities of white than three-fourths give a *light light-gray*, etc. Thus any shade from white to black may be obtained by a mixture of the proper proportions.

170. Limitations of Color Nomenclature. — We use the terms *red, blue, green, pink, pea-green, sky-blue*, etc., very freely, as if they were definite in meaning. The fact of the matter is, they are very indefinite.

For example, could you tell *exactly* what color to get if you were sent to buy *sky-blue* or *pea-green* silk? The trouble is, our terms are not definite, but cover a wide range of color. We still use these indefinite terms for want of better substitutes.

171. Harmony of Color. — In music certain tones sound pleasing when given together. The law governing the combining of these tones is called *harmony*. In the case of colors it is just as true that certain combinations of color are pleasing, while others are not. We speak of this as the *harmony of color*.

So far there are few set rules or laws governing these combinations, since they are left to the taste of the individual. What looks well to one individual may be almost shocking to another.

It is true, however, that the following simple rule can be followed, and that, in general, it will give a pleasing combination. All colors harmonize with black and with white.

172. Half-tone Picture Printing. — In half-tone picture printing a negative is obtained from either the object itself or from a photograph, in exactly the same manner as in photography.

Instead of printing on a sensitized paper as in the case of a photograph, the negative is placed over a sensitized plate of copper or other metal, and the picture is printed on this.

The copper plate is made sensitive by a covering of gelatin sensitive to light, just as in the case of the paper.

Before the printing on the metal plate is begun, two glass screens (*a* and *b*, Figure 128) are placed, one over the other, between the negative and the plate. These screens are usually ruled with from 100 to 150 parallel lines to the inch, and, when placed over one another (*c*), the lines of one are perpendicular to the lines of the other; the lines being scratches which shut off light.

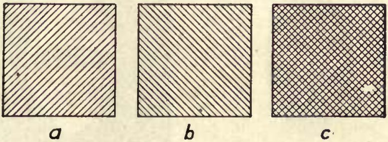

FIGURE 128. — LIGHT SCREENS.

In printing, the light shines through the light part of the negative, turning the sensitive gelatin on the metal plate black, and making it insoluble. The rest of the gelatin is unaffected, and when "washed" dissolves, leaving the black, insoluble part on the plate. The lines of the screens appear as clean lines on the plate.

This metal plate is then subjected to an acid bath which etches, or eats away the unprotected part of the plate, leaving the part covered with gelatin "raised" or level with the original surface.

After scraping off this gelatin the plate may be inked and used for actual printing of pictures in books, magazines, or newspapers.

Since most printing is done from rolls, the impression may be transferred from the metal sheet to the rolls by the electrotype method. (§ 280.)

By referring to Figure 129 it can be seen why the metal plate will produce a picture which is the exact likeness of the object.

The *light* part of the negative represents the *dark* part of the object. The *raised* part of the metal plate represents the *light* part of the negative or the *dark* part of the object, the lines of the two screens appearing as *depressed* parts on the metal plate.

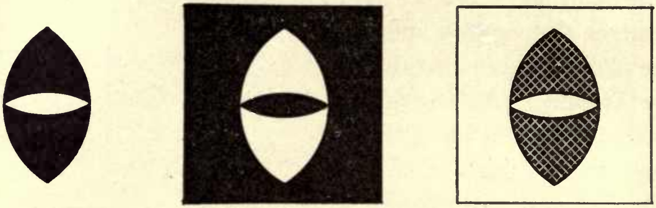
Object *Negative* *Plate*

FIGURE 129. — DIAGRAM SHOWING OBJECT, NEGATIVE, AND PLATE IN HALF-TONE PICTURE PRINTING.

Now, when the metal plate is inked and a picture is printed with it, the raised portion is the only part that prints, thus reproducing the *dark* parts of the object in ink. The lines are to keep the ink from "running." They do not show, except upon close examination, in the printed picture.

173. The Three-color Printing Process. — The half-tone picture printing process, discussed in § 172, gives a picture in light and shadow only. This process has been enlarged upon, and now pictures in *actual colors* can be printed by what is called the "three-color process." This process is used to print the colored cover designs and colored advertisements used so much in the better magazines.

In this process three negatives are taken through three separate light *filters*. The three filters consist of three plates of glass stained *violet, blue-green,* and *orange,* respectively.

These filters are placed in front of the camera, one at a time, when the three negatives are taken. The negatives are developed and printed on three separate metal plates, as in the half-tone process.

These plates, or their reproduced rolls, are then inked, — the one corresponding to the *violet filter* with *yellow* ink, the one corresponding to the *blue-green filter* with *red-orange* ink, and the one corresponding to the *orange filter* with *blue* ink. Then all three are successively printed on the same sheet of *white paper*. The result is a picture of the object in actual colors, or at least approximating the actual colors, the degree of accuracy in colors depending on the trueness of the colors of the filters and inks used.

The reasons why this process gives the actual colors are as follows:

In the first place, the negative taken with a *violet filter* has *dark* spots only where the *violet* light strikes, and so the corresponding metal plate has *depressed* spots representing the *violet of the object.*

Likewise, the metal plate corresponding to the *blue-green filter* has *depressed* spots representing the *blue-green of the object,* and the metal plate corresponding to the *orange filter* has *depressed* spots representing the *orange of the object.*

Now, the three colors, *violet, blue-green,* and *orange,* contain all the colors of white light, and so the depressions in the three metal plates represent all the actual colors of the object.

The plate corresponding to *violet* in the object, covers all the rest of the white paper with *yellow,* the complementary pigment of *violet.* Likewise, the plate corresponding to *blue-green* in the object covers all the rest of the white paper with *red-orange,* and the plate corresponding to *orange* in the object covers all the rest of the white paper with *blue.* The spots with *yellow ink* reflect all colors but *violet,* or, in other words, *blue-green* and *orange.* (Figure 130.) Also, the spots with *red-orange ink* reflect all colors but *blue-green,* or in other words *violet* and *orange.*

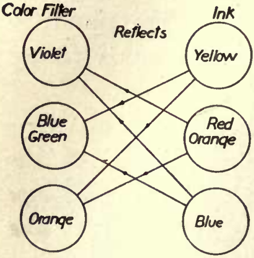

FIGURE 130. — DIAGRAM.

Therefore a spot covered by *yellow* and *red-orange* inks reflects only *orange.* Also a spot covered by *yellow and blue inks* reflects only *blue-green,* and a spot covered by *red-orange and blue inks* reflects only *violet.*

This makes the printed picture reflect the actual colors of the object in the correct positions and amounts.

Review Problems

1. What is the theory of the nature of light?

2. When is a body luminous?

3. Why can you see a body which is not luminous?

4. What is the velocity of light?

5. Explain Roemer's method for determining the velocity of light.

6. Give two comparisons which will show the magnitude of the velocity of light.

7. Give the law of reflection.

8. Does your right hand appear to be the right hand of your image in a plane mirror?

9. Construct the image in a plane mirror. Describe the image.

10. Construct the image in a concave mirror, (*a*) when object is beyond center of curvature, (*b*) when object is at center of curvature, (*c*) when object is between center of curvature and principal focus, (*d*) when object is at principal focus, (*e*) when object is between principal focus and mirror.

11. Give two uses of the convex mirror.

12. Give two uses of the concave mirror.

13. Explain why refraction takes place.

14. Give five applications of refraction.

15. Construct the image in the five different settings of the convex lens.

16. Give an application of each of the five settings of the convex lens.

17. Explain how a photograph is made.

18. What is diffused light?

19. What produces color in a light?

20. Explain why an opaque object has a certain color.

21. Explain why a stained glass has a certain color.

22. Why can you not rely on colors chosen by artificial light?

23. What application has color to the decorating and lighting of a home?

24. Explain why shadows play an important part in the proper illumination of a room.

25. How are half-tones made?

26. What is a tint? What is a shade?

27. What is meant by the " additive method "?

28. What is meant by the " subtractive method "?

29. What is the difference between a dye and a paint?

30. What causes a colored piece of goods to " fade "?

CHAPTER XIII

MAGNETISM

174. Properties of Magnetism. — We do not know just what *magnetism* is, but we do know many things about it. For centuries people have known of a peculiar kind of ore called "*lodestone*," which has the property of attracting iron. The "lodestone" is said to have magnetism, and the best definition we have is: *Magnetism is the property some objects have of attracting iron.* An object which has magnetism is said to be a magnet.

175. Poles of a Magnet. — If a magnet be thrust into a box of iron filings, the filings will cling to the ends of the magnet, and will appear to be attracted to one point near each end. This point is called the pole of the magnet, and is located inside the iron some distance from the end. *The pole of a magnet is the point at which all the force of attraction is centered.*

A magnet has two poles, one near each end, called *north* (*N*) and *south* (*S*). It is unfortunate that they were named "north" and "south," for we are apt to confuse these terms with *direction*. A magnet may be placed in any position, and yet its poles remain the same, regardless of direction. For example, a magnet may be placed in an east and west position, and yet its poles are called *N* and *S*. A magnet may be easily placed so that its N-pole is on the south end (direction) of the magnet.

176. Law of Attraction and Repulsion. — If a magnet is suspended at its middle by a cord, or balanced on a pivot, and another magnet is brought near it, the end of the first magnet is either *attracted* or *repelled* by the other magnet.

If the N-pole of one comes near the S-pole of the other, they are attracted, and if free, will swing together. But if the S-pole of one magnet comes near the S-pole of the other, they are repelled, and if free will swing apart. Thus we have this law: *Unlike poles attract and like poles repel.*

177. The Earth a Magnet. — The earth itself is a huge magnet, one of its magnetic poles being about 1000 miles from the geographical north pole, while the other magnetic pole is at a similar distance from the geographical south pole.

A magnet suspended so that it is free to swing in a horizontal plane will come to rest in a north and south position. This is due to the magnetic attraction of the earth. The pole that swings towards the *north* is called "N-pole," while the one that swings towards the *south* is called "S-pole." At the time the poles were named, people did not know that magnets would ever be used for anything except to tell direction, and the names "*N*" and "*S*" seemed appropriate.

But now the names are confusing. A N-pole is the pole that points north when the magnet is free to swing, but by the "law of attraction" unlike poles attract; therefore the magnetic pole near the north geographical pole is really a "*S*" magnetic pole. Likewise the "*N*" magnetic pole of the earth is in the south.

178. Field of a Magnet. — We have seen that a magnet will attract iron filings even when they are not touching it. What is it that harnesses the iron filings to the magnet, since we cannot see, or feel, anything between them?

Evidently there is some force in the space about the magnet. This space is called the "*magnetic field,*" and is said to be filled with "*lines of force.*"

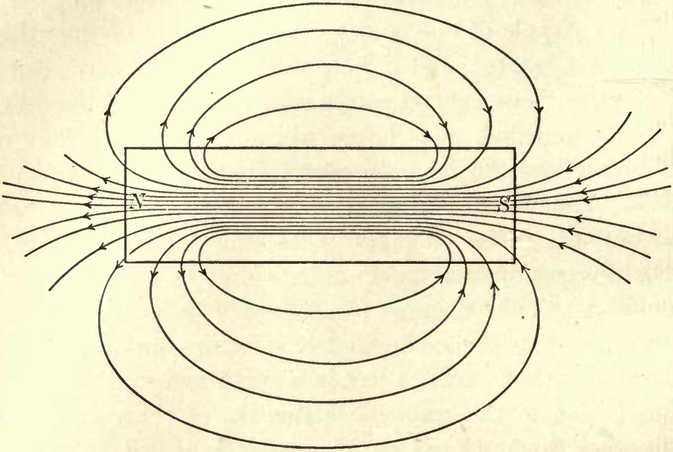

FIGURE 131.—FIELD ABOUT A BAR MAGNET.

Just what these lines of force are no one is able to explain; and for want of a better name they are said to be *strains in the ether*.

If a piece of paper is placed over a bar magnet and iron filings are sifted on it, the filings will arrange themselves in lines as shown in Figure 131.

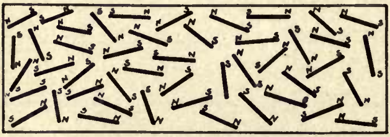

FIGURE 132.—ARRANGEMENT OF MOLECULES IN A PIECE OF IRON NOT MAGNETIZED.

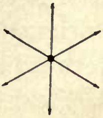

FIGURE 133.—DIAGRAM OF BALANCED FORCES IN A PIECE OF IRON NOT MAGNETIZED.

179. Properties of Lines of Force. — Whatever the lines of force are, they have three known properties:

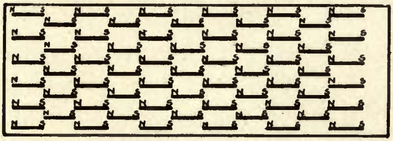

FIGURE 134. — ARRANGEMENT OF MOLECULES IN A MAGNETIZED PIECE OF IRON.

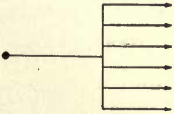

FIGURE 135. — UNBALANCED FORCES IN A MAGNETIZED PIECE OF IRON.

1. They have direction and always come out of a N-pole and go in at a S-pole, completing a loop inside the magnet.

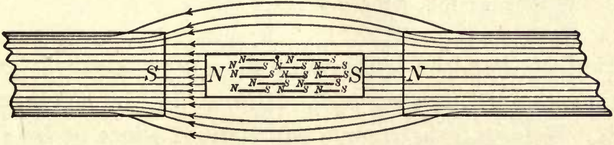

FIGURE 136. — HOW TO MAGNETIZE A PIECE OF IRON.

2. They have a tendency to contract, like rubber bands, and will contract until they are zero in length.

3. They repel one another laterally.

180. Theory of Magnetism. — Some substances are said to be *magnetic*, while others are *non-magnetic*. Magnetic substances are substances whose molecules have N- and S-poles, while non-magnetic substances are those whose molecules do not have N- and S-poles.

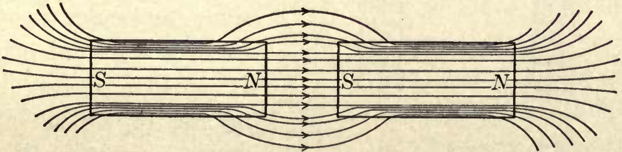

FIGURE 137. — FIELD BETWEEN TWO UNLIKE POLES.

Iron is the most magnetic substance, while cobalt and nickel are only slightly magnetic. Most substances, such as wood, glass, copper, brass, etc., are non-magnetic.

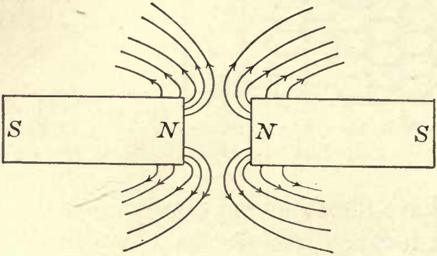

Figure 138. — Field between Two Like Poles.

The fact that iron is magnetic does not necessarily mean that a piece of it is a *magnet*. It must first be *magnetized*.

181. Difference between a Magnetized Piece of Iron and One Not Magnetized.

— In a piece of iron that is not magnetized the molecules have their N-poles and S-poles pointing in various directions (Figure 132), and the effect of some molecules neutralizes the effect of others. It is like several boys pulling in all directions upon a post. (Figure 133.) The pull is balanced and there is no effect on the post.

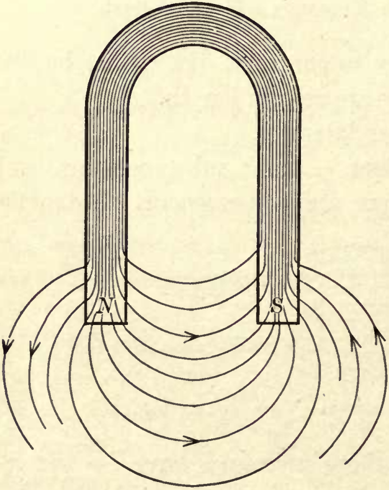

Figure 139. — Field about a Horseshoe Magnet.

But in a piece of iron

which is *magnetized,* the molecules are all in order; so that all the S-poles point to one end, and all the N-poles to the other. (Figure 134.)

In this case the effect of each molecule helps the effect of every other, and one end of the bar becomes a N-pole and the other end the S-pole. To illustrate this as before, all the boys pull in the same direction. (Figure 135.)

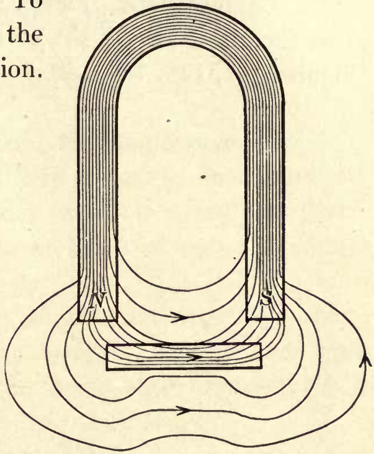

Figure 140. — Field about a Horseshoe Magnet Having a Bar of Soft Iron in Front of Poles.

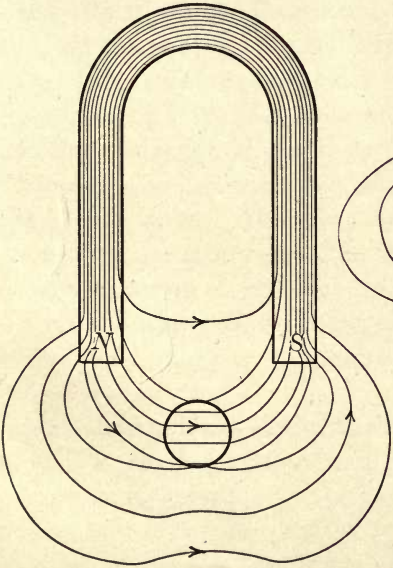

Figure 141. — Field about a Horseshoe Magnet Having a Disk of Soft Iron in Front of Poles.

182. How to Magnetize a Piece of Iron. — To magnetize a piece of iron, place it in a magnetic field so that the lines of force run through the iron. This lines the molecules up as in Figure 136, magnetizing the iron.

If it is a piece of tempered steel that has been magnetized, the molecules will keep their positions, and the steel will *hold* *its magnetism*, because the molecules cannot fall back out of line. This is, then, a *permanent* magnet.

If the piece of iron is soft and not tempered, the molecules become disarranged as soon as the magnetic field is removed; and it loses its magnetism. This is a *temporary* magnet.

183. Characteristic Fields. — The following drawings show the direction of the lines of force in several cases. (Figures 137, 138, 139, 140, 141.)

CHAPTER XIV

ELECTRICITY

184. Relation of Electricity to Magnetism. — Before studying the subject of electricity we spent some time on magnetism, because magnetism and electricity are very closely related. We shall now find how necessary magnetism is to the production of electricity.

The question just what electricity is, has never been satisfactorily answered. The latest theory is that it is some kind of strain in the ether, and that the strain will move along a wire, producing a *current* of electricity.

Anything which will transmit electricity from one place to another is called a *conductor*.

185. Generation of Electrical Pressure. — It has been found that if a conductor is moved in a magnetic field so that it cuts the lines of force *electrical pressure* is produced, or is said to be *generated*.

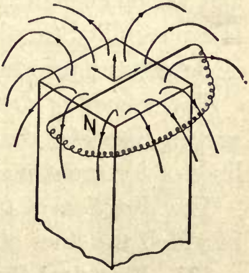

FIGURE 142. — GENERATING ELECTRICAL PRESSURE.

In Figure 142 we have a permanent magnet with the lines of force shown coming out of the N-pole. A copper wire, or rod, is held in this magnetic field and moved *across* the lines of force. This generates electrical pressure in the conductor.

If a complete circuit is made from one end of the bar to the other, a current of electricity will flow.

The thing that produces the pressure is cutting lines of force with a conductor. This, then, is one of the fundamental principles to learn about electricity. *Whenever lines of force are cut by a conductor, electrical pressure is generated.*

186. Nature of Electrical Pressure. — But just what is electrical pressure? Since electricity is an invisible something and yet is analogous to the flow of water, we can best get a conception of it by comparing it to the flow of water.

In the case of water, we say there is a pressure of so many pounds per square inch. Pressure is the thing that makes the water flow when the stop-cock is turned on. The pressure is there whether the cock is turned on or not, and whenever the water has a chance to flow, the pressure forces it to do so.

Electrical pressure is similar. It is that which makes the *electrical current* flow. There may be an electrical pressure, and yet no current (if the circuit is not closed); but if there is a possibility for the current to flow (as when the circuit is closed) the pressure will make it do so.

The *amount of electrical pressure* depends upon the rate of cutting lines of force; or, we could say, upon the number of lines of force cut per second.

The *direction of the pressure* depends upon the direction in which the lines of force are cut.

187. Electrical Current. — The electrical current may be compared to the current of water in a pipe. We say the current is large or small according to the *amount* of water it will deliver in a certain time. Similarly with electricity, *the current is the flow of the electricity, and is measured by the amount of electricity it will deliver per second.*

The size of the current depends upon the pressure forcing it to flow, and upon the resistance offered to it by the conductor.

188. Resistance. — If the water pipe in the above case were small, it would be difficult for the water to get through. In other words, the pipe would offer a resistance to the flow of the water current. The same thing takes place in a wire. *The resistance is that which tends to hold the current back.*

There are four principal things which affect the resistance of a conductor: (1) size, (2) length, (3) kind of material, (4) temperature.

The larger the wire, the smaller the resistance. The longer the wire, the greater the resistance. Some kinds of material have more resistance than others. For instance, copper has less resistance than iron.

Materials which have a low resistance are said to be good conductors. Copper, silver, platinum, and, in fact, nearly all the metals are good conductors. Those materials which have an exceptionally high resistance are called *insulators,* such as air, wood, glass, mica, rubber, asbestos, etc.

The temperature affects different materials differently. With some, it *increases* the resistance; and with others it *decreases* it. A carbon lamp has *less* resistance when hot than when cold, but a tungsten lamp has *more* resistance when hot.

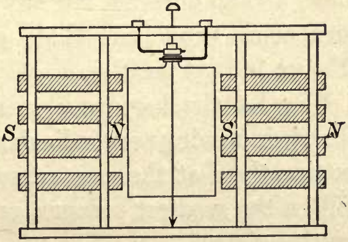

FIGURE 143. — A SIMPLE GENERATOR.

189. The Simple Generator. — Figure 143 shows a loop of wire revolving in a magnetic field. The magnetic field is produced by the permanent magnets *N* and *S*. The lines of force pass from the N-pole across, and into the S-pole. The loop of wire is a conductor; and when it revolves in this magnetic field, it cuts the lines of force, and electrical pressure is generated.

190. A. C. Simple Generator. — Figure 144 shows a cross section of the simple generator. Since it is a cross section, the ends of the loop of wire, where it is cut off, are dots. In this discussion we shall mention only one side of the loop of wire.

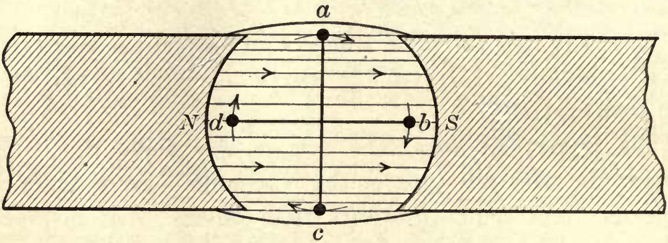

FIGURE 144. — CROSS SECTION OF SIMPLE A. C. GENERATOR.

Suppose we start with the wire at position *a* and turn it around, or revolve the loop at *uniform* speed.

At position *a* the wire is moving parallel to the lines of force, and so does not cut any. Therefore there is no pressure being produced. This can be shown on the curve (Figure 145) at position *a*.

Now let the loop revolve until the same wire is at *b*. Here it is moving perpendicular to the lines of force, and so is cutting them at the greatest rate possible. Therefore there will be the greatest pressure generated, — shown by point *b* on the curve.

Now, when the loop revolves so that the wire is at position *c*, the wire is again moving parallel to the lines of force. Again the pressure is zero, — point *c* on the curve.

As the loop revolves farther, the wire begins to cut the lines of force in the *opposite* direction; and so the pressure will be in the other direction, or will be negative. When the wire reaches position *d*, it is again moving perpendicular to the lines of force, and so is cutting the greatest number again; and so the pressure is highest, but in the *negative* direction, — point *d* on the curve.

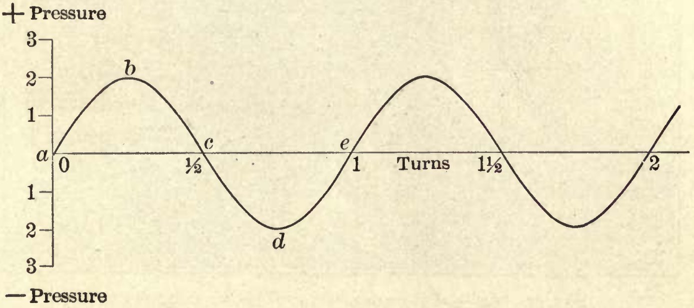

FIGURE 145. — CURVE SHOWING PRESSURE AT DIFFERENT PARTS OF THE TURN OF THE ARMATURE IN AN A. C. GENERATOR.

When the loop completes the turn, the wire is at the same point as when it started, so the effect is the same, — point *e* on the curve.

Reviewing what has just taken place throughout the turn, we find that the pressure started at zero, then gradually increased in the positive direction until the loop had made a quarter turn. Here the pressure was the highest, but immediately began to diminish until at the half turn it had died down until it was again zero. At this position the pressure began to increase, but in the opposite direction, and continued to increase until it reached its highest value at the three-quarters turn; then decreased until it reached zero at the complete turn.

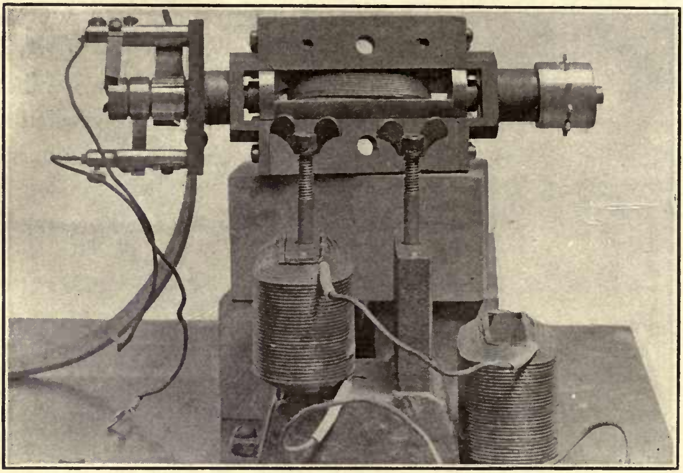

Figure 146. — Photograph of a Hand Generator.

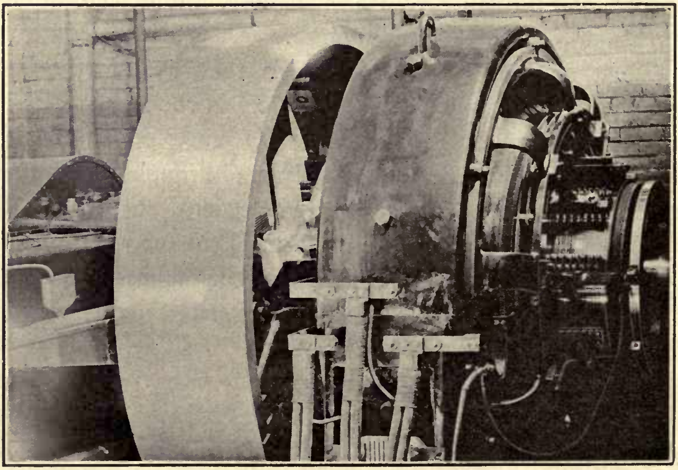

Figure 147. — Photograph of a 300 Horse Power D. C. Generator.

Thus we see that the pressure was first in one direction for half a turn, and then *in the opposite direction for half a turn.* This is called *alternating current pressure,* and it makes the current flow first in one direction throughout the circuit, and then stop and flow in the other direction.

Alternating Current (A. C.) is an electrical current that flows first in one direction and then in the other.

Direct Current (D. C.) is an electrical current that flows in the same direction all the time.

191. Slip-rings. — From the above discussion we see that whenever a loop of wire revolves in a magnetic field, an alternating current is produced in the loop, which is called the *armature.* If this current is taken off just as it is produced, the current will be *alternating,* throughout the outside circuit. Current is sometimes taken off by means of *slip-rings.* Slip-rings are two continuous rings of metal put on the end of the armature, as is shown in Figure 148.

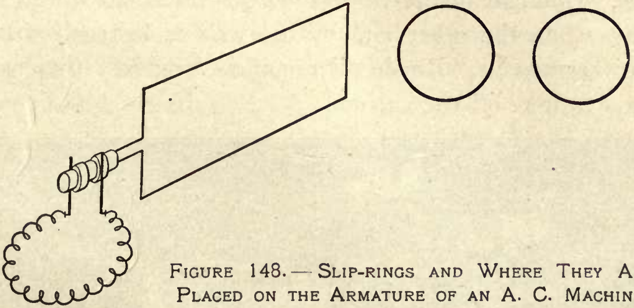

FIGURE 148. — SLIP-RINGS AND WHERE THEY ARE PLACED ON THE ARMATURE OF AN A. C. MACHINE.

The ends of the coil are fastened on these rings, one end on one ring and the other end on the other ring. Metal or carbon "brushes" rest on these rings and pick the current off just as it is made, thus producing an A. C. current in the external circuit.

192. D. C. Simple Generator. — The D. C. simple generator is the same as the A. C. simple generator, except in the way the current is taken off. In the A. C. generator it is taken off by *slip-rings,* while in the D. C. generator it is taken off by a *commutator.*

FIGURE 149. — A COMMUTATOR IS A SLIP-RING CUT IN PARTS.

193. Commutator. — A commutator is the same as *one* slip-ring, except that it is *split.* It consists of two or more segments, as is shown by Figure 149.

This is put on the end of the armature instead of the slip-rings. One end of the loop of wire is fastened to one segment, while the other end of the wire is fastened to the other segment. "Brushes" are placed against these segments to take off the current.

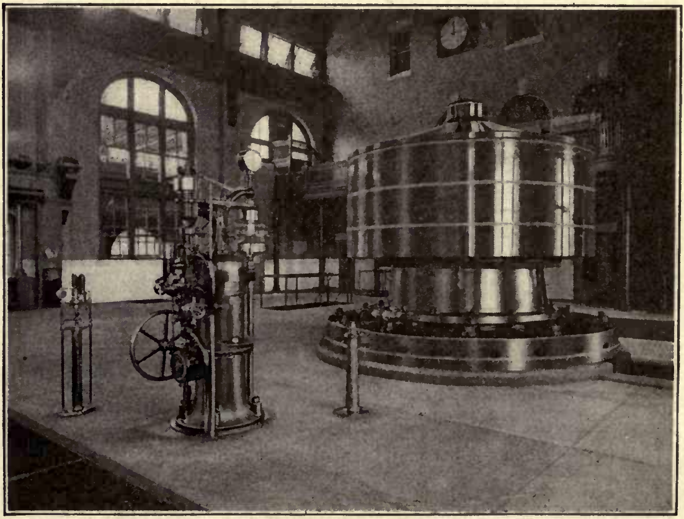

FIGURE 150. — A LARGE GENERATOR AT NIAGARA FALLS, DRIVEN BY WATER TURBINE.

Since the current *alternates* in the loop of wire, first one commutator segment is positive (*i.e.* the current comes out), and then the other. But the brushes are so set that when the current changes in the loop, the brushes slip from one segment to the other; thus one brush is always positive, and the other is always negative. Figure 151 will help to show this change.

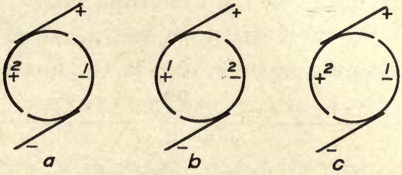

FIGURE 151.—HOW THE COMMUTATOR MAKES A. C. BECOME D. C.

In position *a, number 1, commutator-bar* is on the right, and is negative, while *number 2 bar* is on the left, and is positive. This makes the upper brush positive, and the lower brush negative.

In position *b,* the coil has turned *one-half* the way round, putting *number 1* on the left and *number 2* on the right; but, in turning, the current is reversed, so that now *number 1* is positive and *number 2* is negative. This still leaves the upper brush positive and the lower brush negative.

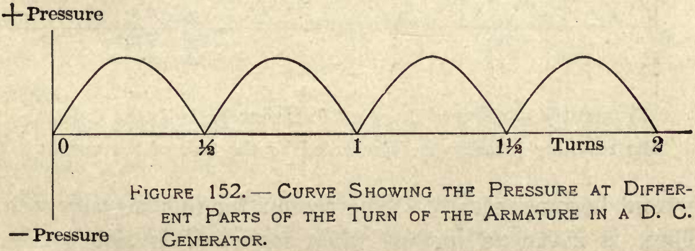

FIGURE 152.—CURVE SHOWING THE PRESSURE AT DIFFERENT PARTS OF THE TURN OF THE ARMATURE IN A D. C. GENERATOR.

In position *c,* the conditions are the same as in *a.* This shows that the current always comes out of the same brush, or has become D. C.

194. Curve for D. C. — Referring back to Figure 145, the curve for the simple generator, we see that the curve changes somewhat when the commutator is put on. It changes to the curve on the preceding page. (Figure 152.)

The first half-turn is the same, but the second half-turn becomes positive, due to the fact that the brushes slip from one bar to the other at the same time the current changes direction.

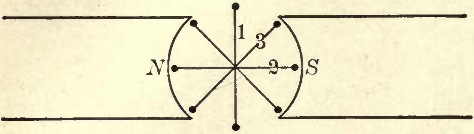

FIGURE 153. — CROSS SECTION OF A GENERATOR WITH 3 COILS.

195. A Pulsating D. C. Made Steady. — From the curve (Figure 152) we see that the current rises and falls with each half-turn of the loop of wire. This is what is called a *pulsating current*. But if, instead of *one* coil of wire, several coils are put on, as in Figure 153, then the current becomes steady. The reason for this is easily seen. There is never an instant when *some* coil is not cutting the lines of force at right angles, thus constantly keeping the pressure at the highest. (Figure 154.)

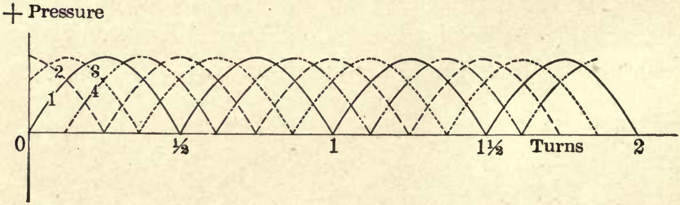

FIGURE 154. — CURVES SHOWING PRESSURE FROM THREE COILS. The resulting pressure is represented by the tops of the curves.

CHAPTER XV

MAGNETIC EFFECT OF AN ELECTRICAL CURRENT

196. Magnetic Field about a Wire Carrying a Current. — We have seen that cutting lines of force by a conductor produces electrical pressure. On the other hand, a current of electricity, like a magnet, has about it a magnetic field.

If a wire carrying a current of electricity be passed through a cardboard (Figure 155), and iron filings be sifted on the cardboard, the filings will arrange themselves, in concentric circles, about the wire. This shows that the current has a magnetic field, and that the lines of force are in concentric circles.

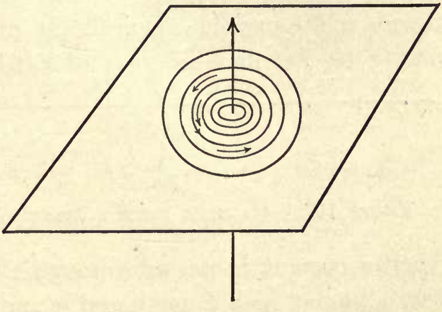

FIGURE 155. — THE FIELD ABOUT A WIRE CARRYING AN ELECTRIC CURRENT.

To determine the *direction* of these lines, use this rule: *Grasp the wire with the right hand, the thumb in the direction of the current, and the fingers will point out the direction of the lines of force.* A magnetic needle set on the cardboard will also show the direction of lines of force. (Figure 156.)

If a wire carrying a current be held over a magnetic needle, the needle will tend to turn at right angles to the wire. (Figure 157.) The following rule can be used to tell which direction the needle will turn: *Extend the fingers of the right hand along the wire with the wire between the palm of the hand and the needle, and the thumb will point the direction the N-pole of the needle will turn.*

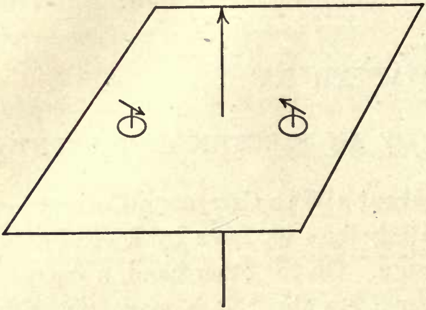

FIGURE 156. — MAGNETIC NEEDLES SHOW DIRECTION OF FIELD ABOUT A WIRE CARRYING AN ELECTRIC CURRENT.

197. Current through a Helix. — A helix is a coil of wire wound round and round in a spiral. It may have a core, or it may not. Let us use a piece of soft iron for a core. Now, when a current is passed through the helix, it makes the iron a magnet with a north and a south pole. (Figure 158.) The coil would become a magnet whether the iron were in it or not, but the soft iron makes the magnet much stronger. Why?

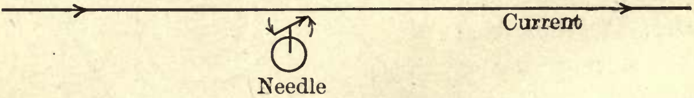

FIGURE 157. — MAGNETIC NEEDLE TURNS WITH THE LINES OF FORCE.

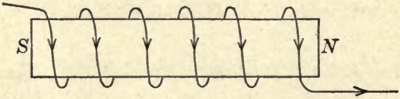

FIGURE 158. — DIAGRAM SHOWING POSITIONS OF POLES OF AN ELECTRIC MAGNET.

To determine the *north pole of an electro-magnet* (for that is what the coil is called), use this rule: *Grasp the coil with* *the right hand with the fingers in the direction of the current, and the thumb will point to the north pole.*

Note that the position of the north pole is determined by the direction which the current takes around the coil. The fact that the current goes in at *one* end or the *other* has nothing to do with the north pole.

198. Electro-magnet. — For a definition of an electro-magnet we can give this: *An electro-magnet is a magnet formed by a current passing around, or near, the magnet.*

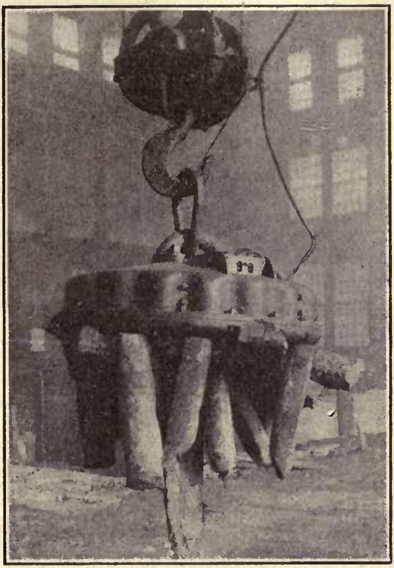

FIGURE 159. — PHOTOGRAPH OF A 2-TON LIFTING MAGNET.

APPLICATIONS OF THE ELECTRO-MAGNET

199. Doorbell and Buzzer. — The doorbell is one of the most common applications of the electro-magnet. The current is started at the battery (*B*, Figure 160); goes through the coils *C*, *C*; then into the vibrator *V*; then into the set-screw *S*; then into the push button *P*; and, finally, back into the battery, forming a complete circuit.

When the push button *P* is held down, the current flows through the circuit, magnetizing the coils *C*, *C*. These coils then attract the soft piece of iron on the vibrator, pulling it away from contact with *S*, and striking the bell with the hammer. As soon as contact is broken, the coils lose their magnetism, and the vibrator flies back in contact with *S*, due to the spring in the vibrator. As long as the button is held down, this operation is repeated again and again, causing a steady ringing of the bell.

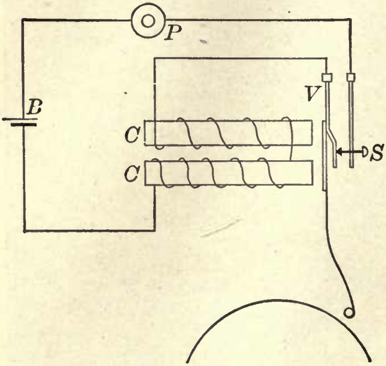

FIGURE 160. — WIRING DIAGRAM OF ELECTRIC DOORBELL.

A buzzer is simply a doorbell with the bell left off. The buzzing sound is made by the vibrator.

200. The Telegraph Sounder. — The telegraph sounder consists of two coils of wire (*C*, *C*) and a soft iron bar (*SI*) supported on a pivot (*P*) in such a manner that a spring (*S*) holds the end of a bar up against a screw (*D*). (Figure 162.)

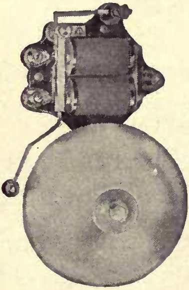

FIGURE 161. — PHOTOGRAPH OF ELECTRIC DOORBELL.

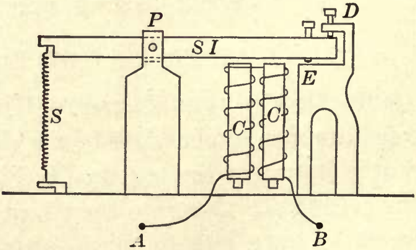

FIGURE 162. — WIRING DIAGRAM OF THE TELEGRAPH SOUNDER.

When a current is sent through the coils *C*, *C* by attaching a battery at *A* and *B*, these coils become magnets and pull the soft iron bar down until it strikes the screw *E*, making a slight sound. The bar is held in this position as long as the current flows; but as soon as the current stops, the coils lose their magnetism, and the bar flips back to *D*, making a loud click. By means of these sounds, the operator is able to read the message.

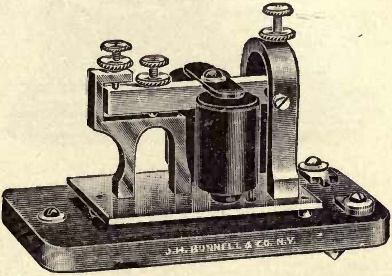

FIGURE 163. — PHOTOGRAPH OF THE TELEGRAPH SOUNDER.

201. Telegraph Relay. — The telegraph relay merely uses the electromagnet to close another electric circuit.

The main current is sent through coils *C*, *C* (Figure 164) by connecting the main line to *A* and *B*. This magnetizes the coils, and they attract the soft bar of iron *SI*, pulling it up into contact with screw *E*. This completes the circuit between *C* and *D*, the binding-posts for the local circuit.

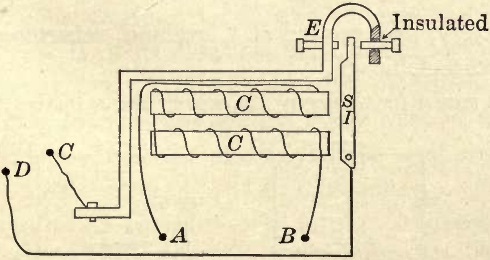

FIGURE 164. — WIRING DIAGRAM OF THE TELEGRAPH RELAY.

202. The Telegraph System. — We have just learned the construction of the sounder and relay, so now we will see how they are put to use in the telegraph system.

Figure 167 shows a system through three cities. At Chicago the main wire is grounded; then a battery (*B*) is put in; and also a key (K) and a relay (R). Next, the wire runs to Toledo; and again a key and a relay are connected in series with the line. It goes then to Cleveland, where still another key, relay, and battery are put in. Then the wire is grounded. This completes the main circuit.

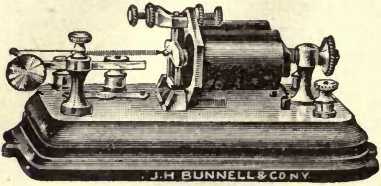

FIGURE 165. — PHOTOGRAPH OF THE TELEGRAPH RELAY.

Tracing the circuit, we start at the ground at Chicago, go through the battery, relay, and key to the key, and relay at Toledo, then through the key, relay, battery, and ground at Cleveland, returning through the ground to Chicago.

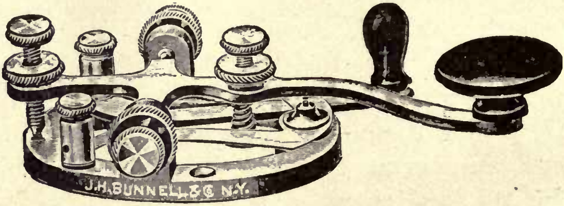

FIGURE 166. — PHOTOGRAPH OF A TELEGRAPH KEY.

Off each relay is run a *local* circuit, in which are a battery

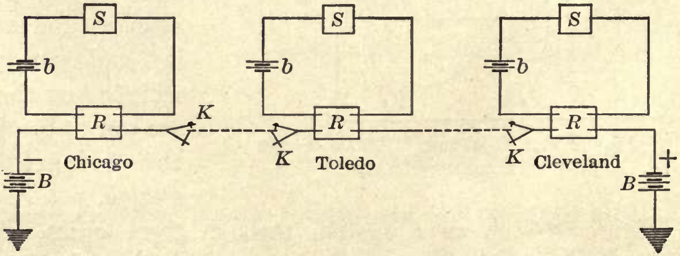

FIGURE 167. — WIRING DIAGRAM OF A THREE STATION TELEGRAPH SYSTEM.

and a sounder. The relay closes the local circuit; and the battery sends a current through the sounder, making it click.

Note that the current in the main line never goes through the sounder.

203. The Electric Clock. — Very often it is desired to have several clocks run exactly together; in other words, to be controlled by a master-clock. This is accomplished by the so-called electric clock. (Figure 168.)

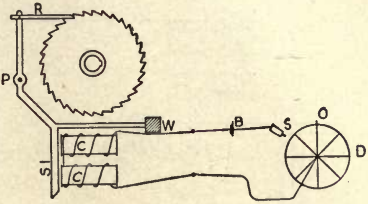

FIGURE 168. — WIRING DIAGRAM OF ELECTRIC CLOCK.

The clock consists of a pair of coils (*C*, *C*) so arranged that when an electric current passes through them they turn the soft iron (*SI*) on the pivot (*P*), making the pawl (*R*) slip down a notch on the ratchet wheel. Then, when the current is stopped, the weight (*W*) turns the bar back, pushing the wheel around one notch. This takes place every minute, thus making the minute hand move one space on the dial.

For sending the current through the coils an electric circuit is made through the master-clock. The master-clock runs a drum (*D*, Figure 168) on which is a peg (*O*). The peg touches the point *S* every minute, thus making a complete circuit through the battery and electric clock.

204. Street Car Circuit-breaker. — As a safety device a so-called *circuit-breaker* is put on street cars. Its purpose is to break the circuit whenever the current becomes too large. It is constructed as in Figure 169.

The current from the trolley comes into the point *a*; then goes through the coil *C*; then to the arm *A*; and out of the contact *K* by point *b*. The current makes a magnet of the coil, its strength depending on the size of the current. If the current becomes sufficiently strong, it lifts the soft iron bar *SI*, tripping the hook *H*, allowing the spring *S* to pull up the arm *A*, thus breaking the circuit. The motorman must then reach up and pull down the arm again before he can start the car.

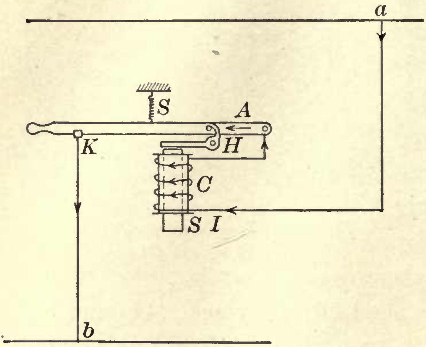

FIGURE 169.—WIRING DIAGRAM OF CIRCUIT-BREAKER.

205. The Annunciator. — The annunciator is an instrument used in office buildings, in elevators, etc., etc., for the purpose of telling at what place the person calling is located. There may be any number of push-buttons, but the diagram (Figure 171) shows an elevator call-system for four floors, or for four push-buttons.

In the annunciator are four coils (*c*, *c*, *c*, *c*), five binding-posts (*a*, *b*, *c*, *d*, and *e*), and the door-bell (*B*).

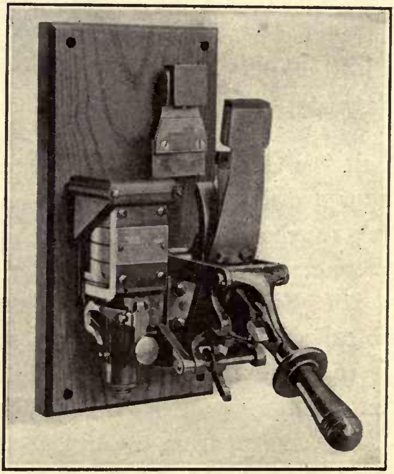

FIGURE 170. — PHOTOGRAPH OF A CIRCUIT-BREAKER.

From the binding-posts *a*, *b*, *c*, *d* run wires through coils *1, 2, 3, 4,* respectively, these wires all being connected with one wire which runs to the bell and finally to the binding-post *e*. This constitutes the internal connection of the annunciator.

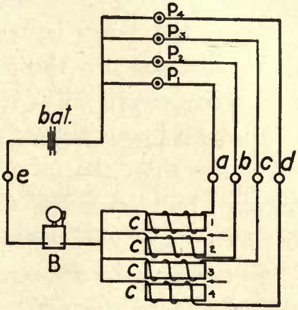

FIGURE 171. — WIRING DIAGRAM OF A FOUR-POINT ANNUNCIATOR.

The external connections are as follows: A battery is attached to the binding-post *e*, and then a single wire is run up to all of the succeeding push-buttons. Then from *each* push-button returns a wire to its respective binding-post, *a, b, c,* or *d*. Whenever a push-button is pushed, it completes the circuit, through the corresponding coil and also the bell. Thus the bell is rung, and the needle below the magnet is drawn over, indicating which push-button was operated.

206. The Automatic Arc Lamp. — The automatic arc lamp, which is used principally to light our streets and large factory buildings, is an application of the electro-magnet. This principle is used automatically to adjust the carbons, which are continually burning off. To light the arc, the carbons must first touch; and then must be drawn just the correct distance apart, and kept there. The operation is as follows:

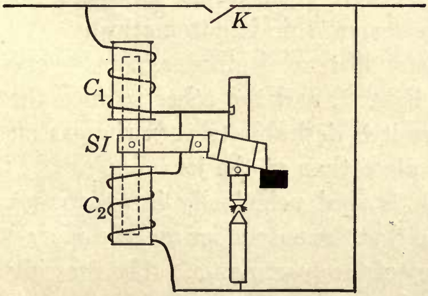

FIGURE 172. — WIRING DIAGRAM OF AN AUTOMATIC ARC LAMP.

The current flows from the line into coil C_1 (Figure 172), and then divides. One part goes to the upper carbon, and the other part goes to the coil C_2.

When the lamp is not lighted, the upper carbon falls down and touches the lower one; thus when the current first starts, nearly all of it flows through the carbons, instead of through lower coil C_2, for the resistance of the carbons is much less than that of coil C_2. Thus upper coil C_1 is magnetized, but lower coil C_2 is not. This pulls the soft iron bar *SI* up, and also the upper carbon which is attached to it.

As the carbons are separated, the light is formed, and at the same time the resistance of the gap becomes more and more, forcing part of the current to flow through coil C_2. Whenever this part becomes strong enough to balance the pull of coil C_1, the carbons are held stationary.

207. Other Applications of the Electro-magnet. — Other applications of the electro-magnet are the automatic telephone, the electric gas-lighter, and the electric door-latch.

The automatic telephone takes the place of the operator at the switchboard. The person calling does so by pressing on a dial at his transmitter, thus calling the number he wishes. No telephone operator is necessary to make the connection, as the electro-magnets do it automatically.

The gas-lighter consists of two electro-magnets, — one to turn on the gas and light it, and the other to turn the gas off. It is used where it is desirable to turn the gas off and on from some other place than at the jet.

The electric door-latch is used principally in apartment houses, and is so arranged that the outer door may be opened by pressing a button in any of the apartments. The pressing of the button closes an electric circuit, causing an electro-magnet to release the latch of the door.

CHAPTER XVI

HEATING EFFECT OF AN ELECTRIC CURRENT

208. Work, Heat, and Electrical Energy. — Work is defined as a force overcoming a resistance and moving it. Work is energy, and so is heat. There are many cases where work is changed into heat. If you slide down a rope, it burns your hands. Your weight forces you down against the friction of your hand on the rope, thus doing work; and this work is changed to heat. Again, if a piece of iron is hammered, it becomes warm. If you stir cake-dough rapidly for some time, it becomes warmer. The work you do is transformed into heat.

The same thing is true when a current of electricity is forced through a wire. The pressure is the force; the current is the thing forced; and the resistance of the wire is the thing that holds the current back. It is just like your weight forcing your body down the rope against the friction; and, as in that case, heat is produced.

Learn this important principle: *When an electrical pressure forces an electrical current through a resistance, heat is generated.*

209. Electrical Units. — Electrical quantities are definite, just like *distance, weight, time, etc.;* so it is necessary to have units to measure them.

The following table gives the thing to be measured, the unit of measurement, and the letter used to stand for it:

Thing to be Measured	Unit	Letter
Pressure	Volt	E
Current	Ampere	I
Resistance	Ohm	R
Power	Watt Kilowatt	W Kw
Electrical Energy	Watt-hour Kilowatt-hour	W-hr. Kw-hr.

It will be noted that *power* is a new term, and that it has two units — watt and kilowatt. The kilowatt is the larger unit, and is 1000 watts.

Electrical power is the time rate of delivering electrical energy.

The electrical power is found by multiplying the pressure by the current; or

$$\textit{Watts} = \textit{Volts} \times \textit{Amperes}.$$
$$W = E \cdot I.$$

$$\textit{Number of Kilowatts} = \frac{\textit{Number of Volts} \times \textit{Number of Amperes}}{1000}$$

$$\text{or } Kw = \frac{E \cdot I}{1000}$$

The electrical energy is found by multiplying the *power* by the *time*, or

$$\textit{Watt-hours} = \textit{Watts} \times \textit{Hours}.$$
$$W\text{-}hr. = W \times t.$$
$$\textit{Kilowatt-hours} = \textit{Kilowatts} \times \textit{Hours}.$$
$$Kw\text{-}hr. = Kw \times t.$$

The terms *electrical power* and *electrical energy* are often confused. Be sure to get the distinction.

Electrical power is the rate of delivering energy. It is *the pressure at a certain instant* × *the current at the same instant.*

On the other hand, *electrical energy* is a certain amount of energy which is actually delivered. It is not the *rate* of delivering the energy, but is the energy *itself*. The *power* must work for a certain *time* to give energy. Which do you pay for when you pay your light bill, power or energy? Does it make any difference whether a 40-watt lamp burns 1 hour or 3 hours?

Problems

1. What power is being used when a carbon lamp taking .5 ampere is placed on a 110-volt circuit?

2. What is the power used when an iron takes $5\frac{1}{2}$ amperes on 110 volts?

3. State, in words, how to find the power in watts and in kilowatts, having given the current and voltage.

4. Find the cost of running ten 40-watt lamps for 5 hours, if electricity costs 10 cents per Kw-hr.

5. Figure your monthly light bill, if you run, on an average, 4 lamps of 40 watts each, three hours each day; an iron taking 5 amperes for 2 hours, 4 times a month; and a motor taking 3 amperes for 1 hour, 10 times a month. Your lighting circuit is 110 volts, the month has 30 days, and the price of electricity is 9 cents per Kw-hr.

210. Ohm's Law. — A great scientist by the name of Ohm worked out this very fundamental law, known as *Ohm's Law:*

Voltage = Current × Resistance, or

$$E = I \cdot R. \qquad (1)$$

Which may also be written:

$$I = \frac{E}{R} \qquad (2)$$

$$R = \frac{E}{I} \qquad (3)$$

By these three equations it is possible to find voltage, current, or resistance, if the other two quantities are given. Always be sure to choose the one which will answer the question to your problem.

Problems

1. What current will a lamp take on a 110-volt circuit, if its resistance is 220 ohms?

2. What current would the lamp above take if placed on a 220-volt circuit?

3. What current would a lamp take on a 110-volt and a 220-volt circuit, respectively, if its resistance were 44 ohms?

4. What voltage is necessary to send 6 amperes through an iron, if its resistance is 15 ohms?

5. What is the resistance of a stove, if it takes 5.5 amperes on 110 volts?

6. The resistance of the heating-element of an iron increases when it gets hot. When does it take more current, hot or cold?

7. A carbon lamp takes .5 ampere on a 110-volt circuit, while a tungsten takes .315 ampere on the same circuit. Which one has the higher resistance, and how much?

8. A dimmer on a lamp cuts the current down from .315 ampere to .2 ampere. What is the resistance of the dimmer, if the lamp is on a 110-volt circuit?

APPLICATION OF HEATING EFFECT OF AN ELECTRIC CURRENT

211. The Carbon Incandescent Lamp. — The carbon incandescent lamp was one of the first electric lamps used, and, like all the later lamps, it uses the heating effect of an electrical current to produce the light, the principle being to force a large enough current through a carbon wire to heat it to incandescence.

The lamp consists of a glass bulb from which the air has been exhausted. (Figure 173.) Inside the bulb is the carbon wire through which the current must pass. This wire makes connection through the end of the bulb by means of small pieces of platinum wire, platinum being used because its coefficient of linear expansion is nearly that of glass. Other materials would cause the glass to break when it was heated or cooled.

The glass bulb is sealed with wax into a screw tip, — one end of the wire being attached to the side of the tip, while the other is attached to a small piece set in the middle of the tip. By this means the two ends of the wire are insulated from one another. Contact is made through the lamp by screwing it into a lamp-socket. The screw of the socket is one side of the line, and the middle portion is the other side of the line.

FIGURE 173. — WIRING DIAGRAM OF A CARBON LAMP.

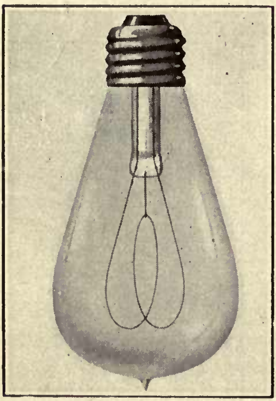

FIGURE 174. — PHOTOGRAPH OF A CARBON LAMP.

Carbon lamps can be used on either D. C. or A. C. They are made for almost any voltage (although care must be taken to get the correct voltage for the circuit in question), and take about $3\frac{1}{2}$ watts per candle power.

212. The Tungsten Incandescent Lamp. — This lamp is constructed like the carbon lamp, except that the wire filament is made of tungsten instead of carbon. Figure 175 shows the tungsten lamp.

The tungsten has almost replaced the carbon lamp, for it takes about one-third as much electrical power to light it and costs very little more for the lamp itself. The objection at first to the tungsten lamp was that its filament was so fragile.

FIGURE 175. — WIRING DIAGRAM OF A TUNGSTEN LAMP.

The filaments of the first lamps were made by grinding the tungsten to a powder, making a paste of it and squeezing it through holes, and then baking it. These filaments broke with the least jar. Lately manufacturers have learned to draw the tungsten metal into wires for filaments, and these are even more durable than the old carbon filaments.

This lamp can be used the same as the carbon lamp, but it takes only about $1\frac{1}{4}$ watts per candle power.

213. The Gas-filled Lamp. — The gas-filled lamp is a tungsten lamp with the bulb filled with a gas, usually *argon* or *nitrogen,* instead of having it a *vacuum.* The filament is put into a more compact coil, so that this lamp is used especially with a reflector.

The gas-filled lamp can be used in any place that the carbon or tungsten can, and takes about 1 watt per candle power.

Lamps of 100 watts rating, or over, are usually filled with nitrogen, while lamps of lower ratings are usually filled with argon.

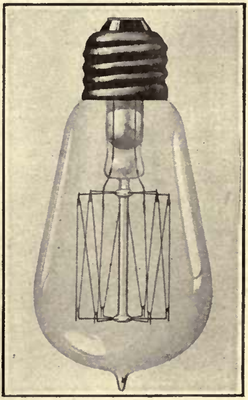

FIGURE 176. — PHOTOGRAPH OF A TUNGSTEN LAMP.

214. The Mercury Vapor Lamp. — This lamp consists of a long glass tube, nearly exhausted of air and containing a small quantity of mercury. In each end platinum wires are sealed, making connections with the electric circuit. (Figure 177.)

To light the lamp, the tube is brought to a horizontal position, so that the mercury makes contact from one end of the tube to the other. As soon as contact is made, the tube is tilted so as to make the mercury flow to one end. This breaks contact, and at this point the mercury is vaporized by the heating effect. This vapor fills the tube, acting as a conductor for the current. The current passing through the vapor heats it to incandescence, giving off a bluish-green light. Some mercury vapor lamps are lighted by other means than tilting, but they all use the same principle for producing the light.

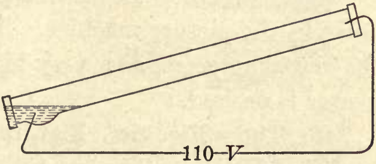

Figure 177. — Wiring Diagram of a Mercury Vapor Lamp.

This lamp is used especially in lighting large buildings, such as factories; for taking photographs; and for rectifying A. C. electricity for storage batteries.

215. The Arc Lamp. — We have already spoken of the arc lamp (Figure 172), but since it is an application of the heating effect of an electrical current, as well as of an electromagnet, we mention it here.

The method of lighting is very much the same as in the mercury vapor lamp. To light it, the carbons must touch, allowing the current to flow through them. Then the carbons must be pulled apart, breaking the electric circuit.

At the point where the circuit is broken, a high resistance is entered. The current flowing through this high resistance produces heat sufficient to vaporize the carbon at that point. This carbon vapor acts as the conductor, and is heated to incandescence, giving off a very bright and powerful light. The temperature reaches as high as 3500° C. and gives about 1 candle power per watt.

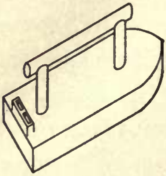

FIGURE 178. — DIAGRAM OF ELECTRIC FLAT-IRON.

Arc lamps are used to light streets and large buildings. They are usually placed, 100 lamps in a series, on a 5000-volt line, taking from 6 to 9 amperes. They will work either on A. C. or D. C.

In moving-picture houses the arc lamp is used in the picture machine. These arcs usually take from 50 to 100 amperes, as a very high candle power is desired.

216. The Electric Flat-iron. — The electric flat-iron (Figure 178) is very much like the ordinary flat-iron, except that it has a heating element and an attachment to connect it to the lighting system.

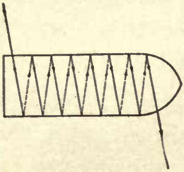

FIGURE 179. — HEATING ELEMENT IN AN ELECTRIC FLAT-IRON.

The heating element is a special kind of wire of high resistance wound on an insulator and placed inside the iron. Very often nichrome wire is wound on a piece of mica (Figure 179), and this is then placed between sheets of mica. The mica acts as an insu-

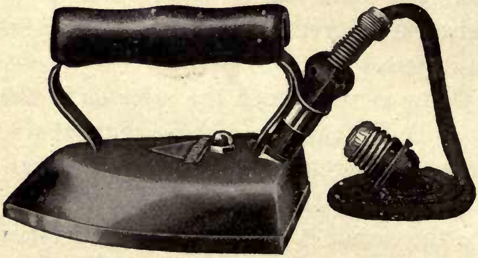

FIGURE 180. — PHOTOGRAPH OF ELECTRIC FLAT-IRON.

lator. Connection is made through a duplex (*double*) wire attached to a plug, which can be screwed into an ordinary lamp-socket.

It is better, however, to have a special socket for the iron, as the current used is often large enough to burn out the connection in an ordinary socket.

The pressure forcing the current through the heating element produces the heat, and as the current is turned on while using, the iron remains hot.

If the iron does not get hot enough, it may be fixed by short-circuiting one turn of its heating element, thus letting through more current. If it gets too hot, another turn may be added. Why?

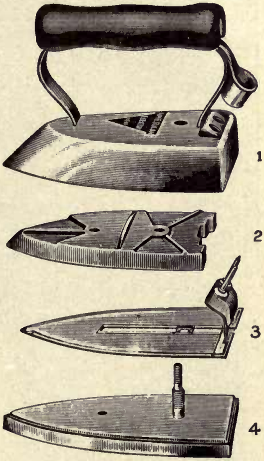

FIGURE 181.—PARTS OF AN ELECTRIC FLAT-IRON.

1. Cover and handle. 2. Cast iron plate that fits over heating element. 3. Heating element. 4. Base on which heating element rests.

217. Other Applications.—Along with the flat-iron come many other electrical heating appliances. Some of these are the toaster, curling iron, stove, coffee percolator, and soldering iron. Any, and all, of these can be used on A. C. or D. C., and can be bought for different voltages, although the standard voltage is 110.

The amount of current taken by these appliances varies with the appliance. A toaster usually requires from 1 to 3 amperes; a curling iron from $\frac{1}{2}$ to 1 ampere; a stove from 3 to 10 amperes; a percolator from 2 to 5 amperes; and a soldering iron from 1 to 2 amperes.

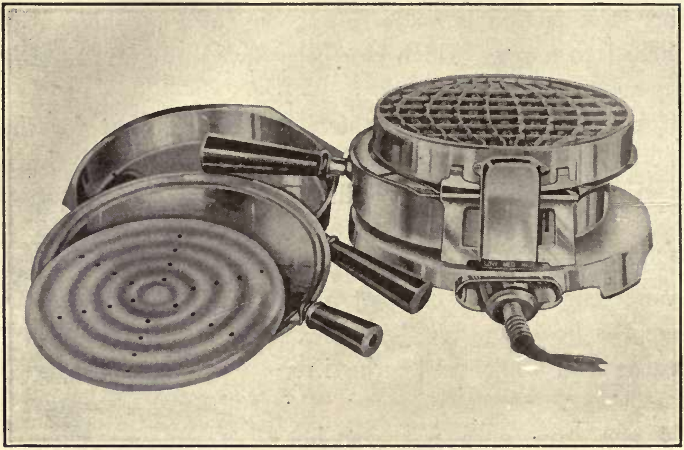

FIGURE 182. — AN ELECTRIC GRILL.
Can be used for several methods of cooking.

FIGURE 183. — ELECTRIC COFFEE PERCOLATOR.

FIGURE 184. — ELECTRIC COOK STOVE.

Electrical heating appliances are coming more and more into common use, principally from the fact that they are very convenient and at the same time are so clean and sanitary. Even the electric cook stove is now quite common. It has become so, largely because it does away with objectionable coal and gas fumes.

Figure 185. — Electric Ironing Machine. Heated and Run by Electricity.

Electric cars are commonly heated by electric registers, and electric heaters are often used in homes, especially to heat small rooms, like bathrooms. During weather which is too warm to require a furnace fire, and yet is too cold to keep the house comfortable without a little heat, electric heaters leave the air purer than those which burn gas or oil.

In buying any electrical appliance, care should be used to get a good one, as the extra cost at the beginning is soon saved in the saving of electrical energy to run it.

CHAPTER XVII

MOTION-PRODUCING EFFECT OF AN ELECTRIC CURRENT

218. How Motion is Produced. — We saw in the case of a coil of wire revolved in a magnetic field that a current was produced in the coil. The reverse of this is also true. If a coil of wire is put into a magnetic field and a current is sent through the coil, it is made to revolve. With the aid of Figure 186 we will show why it will revolve, and in which direction the motion will take place.

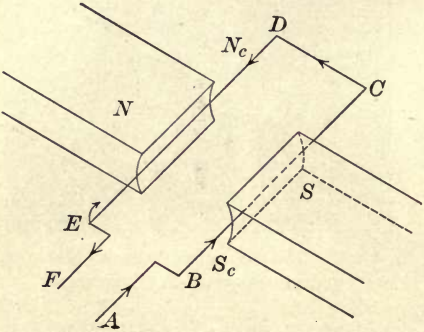

FIGURE 186. — HOW MOTION IS PRODUCED BY ELECTRICITY.

Let the current go through the coil in the direction *A B C D E F*. Then the coil becomes a magnet with its north pole (N_c) at the *top* face of the coil, and its south pole (S_c) at the *bottom* face of the coil.

Now, since like poles repel and unlike poles attract, the coil is made to revolve clockwise, or in the direction of the small arrow at *E*. Thus we see that the coil is made to turn and that the turning effect is due to attraction and repulsion of magnetic poles.

APPLICATION OF MOTION-PRODUCING EFFECT OF AN ELECTRIC CURRENT

219. The Galvanometer. — The galvanometer is an instrument used to detect an electrical current in a conductor. It consists of a coil of wire (*C*, Figure 187) suspended between the poles (*N* and *S*) of a permanent magnet by means of a phospor-bronze ribbon ending in a small spring at the bottom.

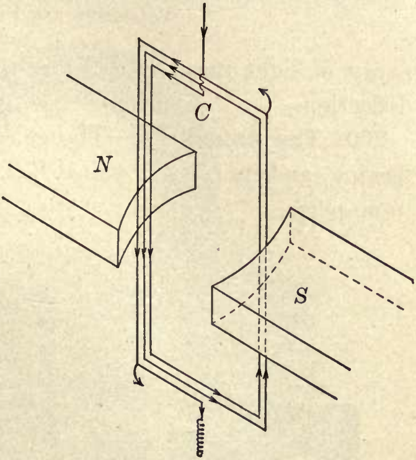

FIGURE 187. — WIRING DIAGRAM OF A GALVANOMETER.

The current to be detected is sent through the coil making it an electro-magnet. If the current passes downward, as the arrow indicates, the north pole of the coil is to the left of the coil.

The permanent S-pole then attracts it, and the coil is made to turn as the arrows indicate.

If it were not for the spring, the coil would turn until its north pole would be directly in front of the permanent S-pole, and would then stop. But the spring allows it to turn only so far as the strength of the poles forces it. Since the strength of the poles depends upon the current flowing in the coil, the deflection of the coil indicates not only that there is a current, but its relative strength.

To make the reading of the deflection easy, a pointer is attached to the coil (or sometimes a mirror is used, so that

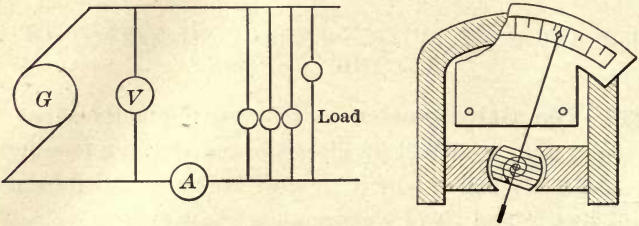

Figure 188. — Wiring Diagram Showing where Ammeter and Voltmeter are Placed.

a ray of light may be deflected), showing the amount of deflection.

220. The Ammeter. — The galvanometer detects current flowing, and its relative value, but does not give its amount in amperes.

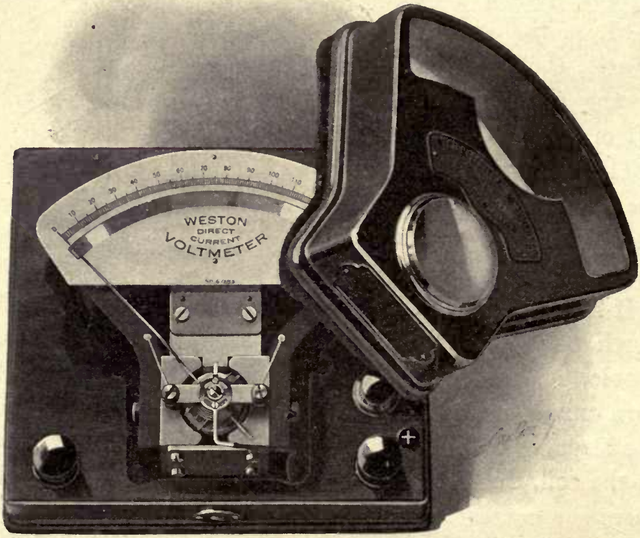

Figure 189. — Photograph of a Voltmeter with the Cover Removed.

When the galvanometer has its scale graduated in amperes, it is called an *ammeter*. Its principle is just the same as the galvanometer, but reads directly in amperes.

The resistance of the coil in an ammeter is *very low*, so that it must always be placed *in the line* (*A*, Figure 188), and *never across the line*.

221. The Voltmeter. — The voltmeter is also like the galvanometer, consisting, as it does, of permanent magnets (D. C. meter) and a suspended coil. The scale of the voltmeter is graduated to read directly in volts.

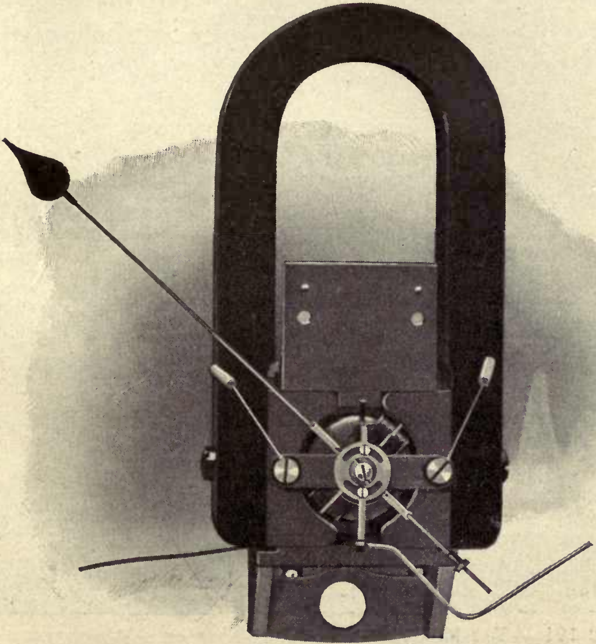

FIGURE 190. — THE PERMANENT MAGNET, COIL, AND POINTER OF A D. C. VOLTMETER.

The resistance of the voltmeter is made *very high;* so it should be placed *across,* not *in,* the line (*V*, Figure 188).

This resistance is made up of the resistance of the movable coil of the instrument. When a high resistance is desired fine wire with a large number of turns is used, but when a low resistance is needed the coil is wound with a coarse wire with few turns.

It is essential that you know how to connect a voltmeter and an ammeter correctly. Should you put the ammeter *across* the line, it will be *burned out.* Should you place the voltmeter *in the line,* it will shut off almost all the current.

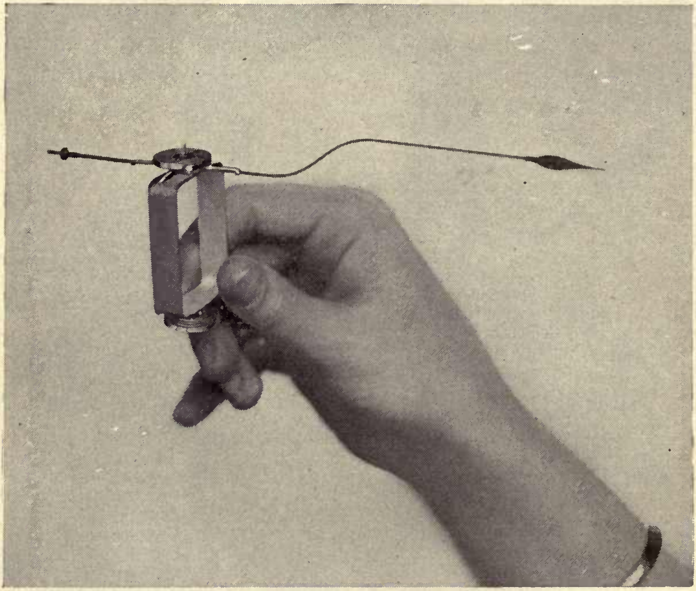

FIGURE 191. — THE MOVABLE COIL AND POINTER OF A VOLTMETER.

222. The Wattmeter. — The wattmeter is an instrument made to read the *power* used in a line. It consists of *two*

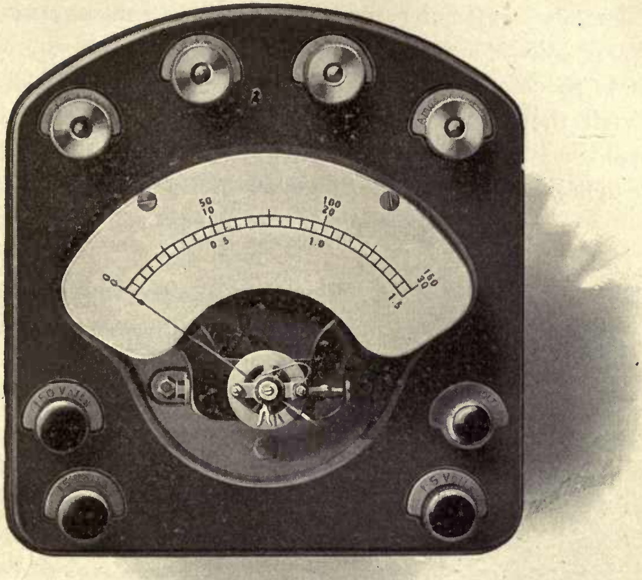

Figure 192.—A Volt-ammeter which can be used as either a Voltmeter or an Ammeter.

The metal binding posts are ammeter connections, and the rubber ones are voltmeter connections.

sets of coils. One set takes the place of the permanent magnets in the *ammeter*, *voltmeter*, and *galvanometer*, and the other coil is movable, as in the above instruments.

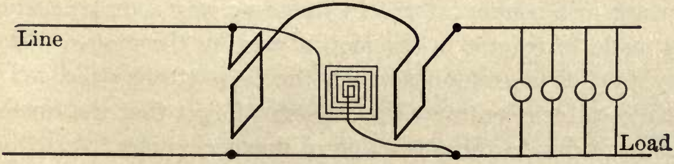

Figure 193.—Wiring Diagram of a Wattmeter.

Since the wattmeter measures power, it must read in *watts,* or *volts* × *amperes.*

It is so connected (Figure 193) that the current passes through the field coils, measuring the current; and the movable coil is connected *across the line,* measuring the volts. The deflection then reads

Volts × *Amperes* = *Watts.*

223. Meters for A. C. Electricity. — The meters here described are for D. C., although the *wattmeter* will work on either A. C. or D. C. But a special kind of ammeter and voltmeter must be made for A. C. They must have electro-magnets, instead of permanent magnets.

224. D. C. Motors. — We have shown how a loop of wire with a current in it tends to revolve when placed in a magnetic field. But its tendency is to revolve no farther than to bring the face of the coil which is a N-pole opposite the S-pole of the field magnet, and to remain in this position.

Now, if the current is reversed in the coil, the face which was a N-pole becomes a S-pole, and vice-versa; and the coil is made to revolve another half-turn. If the current is again reversed, the coil makes another half-turn; and so on. Thus the coil is made to turn continuously by reversing the current in the loop every half-turn.

You will remember that the alternating current generated in the loop of wire of the generator was made direct by means of a commutator. In the same way a direct current is made to reverse in the loop of wire in the motor. Thus by putting a commutator on the loop of wire the coil is made to turn continuously. Do not forget that the turning effect is due to the attraction of magnetic poles.

The difference between a generator and a motor is this:

the generator is supplied with mechanical energy, and transforms it into electrical energy; while a motor is supplied with electrical energy, and transforms it back to mechanical energy. A direct current generator may be used also as a motor.

225. The Watt-hour Meter. — The principle of the watt-hour meter is the same as the wattmeter, but instead of the movable coil being held in position by a spring it is allowed to turn around freely, as a motor. Geared to the movable coil are small hands which pass over dials, just as in the gas-meter.

With one turn of the coil one watt-hour is registered on the dial; but this is such a small unit that it cannot be detected. One thousand turns make a kilowatt-hour, and this is indicated by 1 on the first dial.

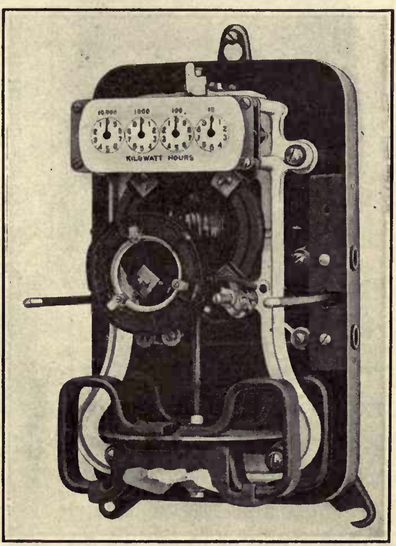

Figure 194. — A Direct Current Watt-hour Meter with Cover Removed.

The reading of the watt-hr. meter is the same as the gas-meter (refer to gas-meter, § 69).

At the bottom of the meter is an aluminum disk revolving between permanent magnets. This disk acts as a brake, so that the coil revolves at a speed proportional to the watts used; it also stops the meter when the current is turned off;

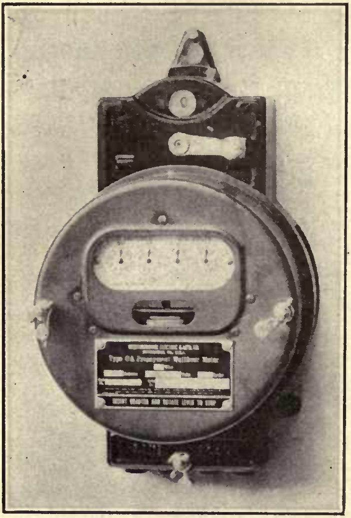

FIGURE 195.—AN ALTERNATING CURRENT WATT-HOUR METER.

otherwise the coil would coast and register watt-hours which were never used.

Watch your meter at home speed up when lights are turned on and slow down when they are turned off. It should stop when all appliances are off; and if it does not, have it reported, as you are paying for electricity not used. Be sure that you can read your meter, and then check your light bills.

226. The Starting-box.—The resistance of a motor is very small, usually not over $\frac{1}{2}$ ohm. If it were attached directly to the line, as is shown by Figure 196, the coils of the motor would be burned out. The reason for this is easily seen. If the voltage is 110 volts and the resistance is $\frac{1}{2}$ ohm, the current would be $\frac{110}{\frac{1}{2}} = 220$ amperes, which would burn out the coils.

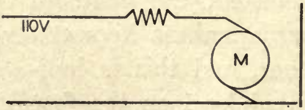

FIGURE 196.—WIRING DIAGRAM OF A MOTOR DIRECTLY ACROSS THE LINE.

In order to protect the motor when starting, a "starting-box" is used. This is made up of coils of resistance wire placed in a convenient box, so that the coils may be cut out of the circuit by merely moving a handle over to the right. (Figure 197.)

The first coil begins at notch *No.* 1 and ends at *No.* 2. The second coil starts at *No.* 2 and ends at *No.* 3, and so on. When the arm is on *No.* 1 notch the current must pass through all five coils. As the arm is moved to the right, coils are cut out.

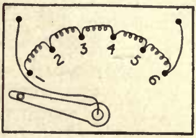

FIGURE 197.—WIRING DIAGRAM OF A SIMPLE STARTING-BOX.

227. C. E. M. F. — It is easy to see why the starting-box keeps the current small, and thus protects the motor while the coils are all in the circuit; but it is not so easy to see why the current does not get large when the coils are cut out.

You will remember that we said that whenever lines of force are cut by a conductor an electric pressure is generated. Now, a motor, when running, has loops of wire (the armature) turning in a magnetic field (field), and thus an electric pressure is generated. This pressure is in the *opposite direction* to the applied pressure or *E. M. F.*, and is hence called *counter-E. M. F.* or *C. E. M. F.*

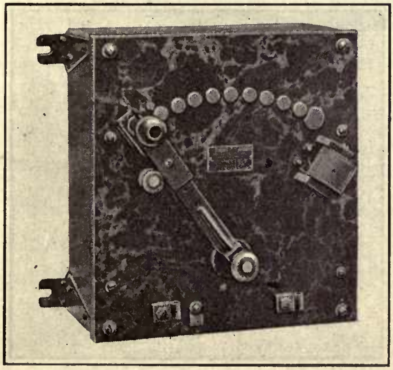

FIGURE 198.—PHOTOGRAPH OF A 3-POINT STARTING-BOX.

A motor, then, when running, generates a *C. E. M. F.* which opposes the applied *E. M. F.*, thus neutralizing part of it. On account of this, the coils of the starting-box may be cut out, as the *C. E. M. F.* holds the current down when the motor has gotten up to speed.

Suppose the motor mentioned above generates 100 *volts*, *C. E. M. F.*, when running at full speed,

then $\frac{110-100}{\frac{1}{2}}=\frac{10}{\frac{1}{2}}=20$ *amperes*, the amount of current the motor would take when running at full speed.

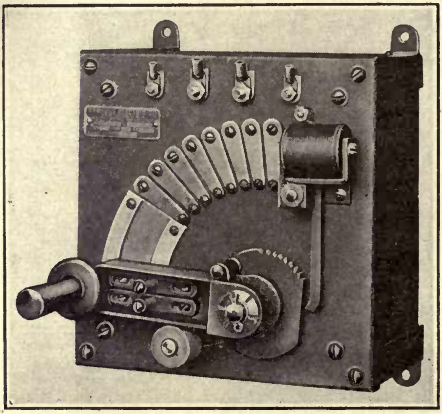

FIGURE 199. — PHOTOGRAPH OF A 4-POINT STARTING-BOX.

228. Series Motor. — There are three general classes of D. C. motors: *Series, Shunt,* and *Compound.* We shall discuss only the first two.

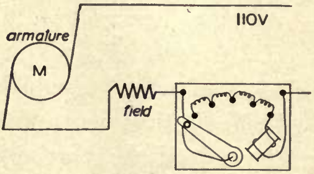

FIGURE 200. — WIRING DIAGRAM OF A SERIES MOTOR WITH STARTING-BOX IN THE CIRCUIT.

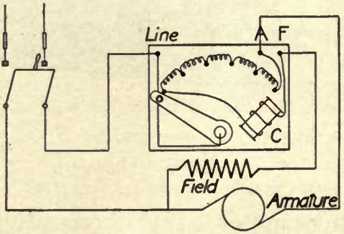

FIGURE 201. — WIRING DIAGRAM OF A SHUNT MOTOR WITH STARTING-BOX CONNECTIONS.

Figure 200 shows the connection for a series motor with starting-box in the circuit.

The term *series* is used because the armature and field are connected in series. The starting-box is put *in the line,* in series with the armature and field.

The speed of the series motor is regulated by putting a resistance in series with the motor. To make the motor run fast, *cut out* resistance; and to make it run slowly, *put in* resistance. Why?

Series motors are used where the motor must start under load, as in the case of a street car or an elevator. Why?

229. Shunt Motor.— The term *shunt* is used because the armature and field are placed in "shunt," or parallel. Figure 201 shows the connections of a shunt motor with starting-box attached.

FIGURE 202.—VACUUM CLEANER DRIVEN BY AN ELECTRIC MOTOR.

The current comes in at the switch, passes to the point on the starting-box marked "*Line.*" From the point marked "*A*" a wire leads to the armature; and from the point marked "*F*" a wire goes to the field. The other ends of the field and armature are connected together, and then attached to the other side of the line at the switch.

Inside of the starting-box, a wire goes from the point marked "*Line*" to the arm. From the *last* notch goes a wire to the point marked "*A*," and from the *first* notch goes a wire to a small coil *C*, and then to the point "*F*."

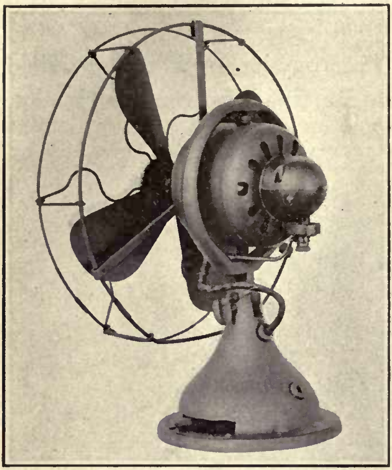

Figure 203. — An Electric Fan.

To start the motor, close the switch; then move the arm of the starting-box slowly to the right, allowing the motor to pick up speed.

This cuts out the resistance in the armature circuit, making the armature turn faster; and at the same time it puts resistance into the field circuit, which also makes the armature turn faster. (Why?) The small coil acts as a magnet and holds the arm over when it is pushed far enough.

Figure 204. — A Small Electric Motor Used to Drive a Sewing Machine.

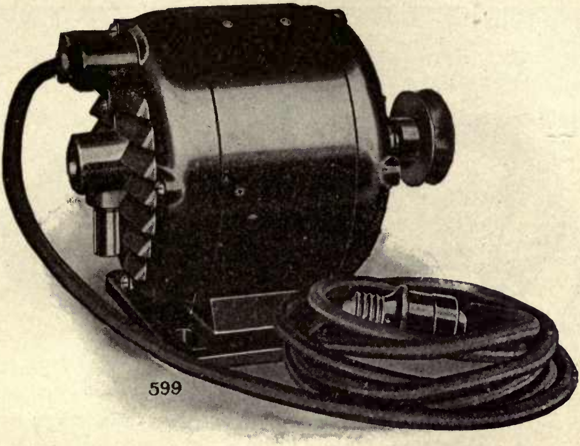

FIGURE 205. — AN ELECTRICAL MOTOR DESIGNED TO RUN A WASHING MACHINE.

The speed is regulated by putting a resistance into the field circuit. *Putting in* resistance makes the motor speed up. *Taking out* resistance makes it slow down. It may seem unreasonable at first that *putting in* resistance in series with the field of a shunt motor speeds it up, and *taking out* resistance slows it down.

The reasons for these characteristics are readily understood, however, when it is remembered that the thing that does most to control the current through a motor is the *C. E. M. F.* which it generates.

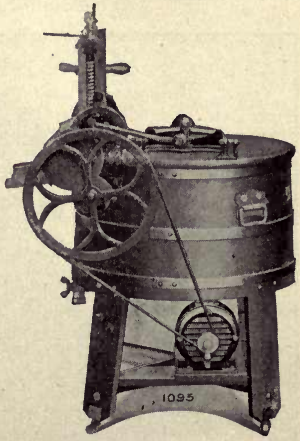

FIGURE 206. — AN ELECTRICAL MOTOR ATTACHED TO A WASHING MACHINE.

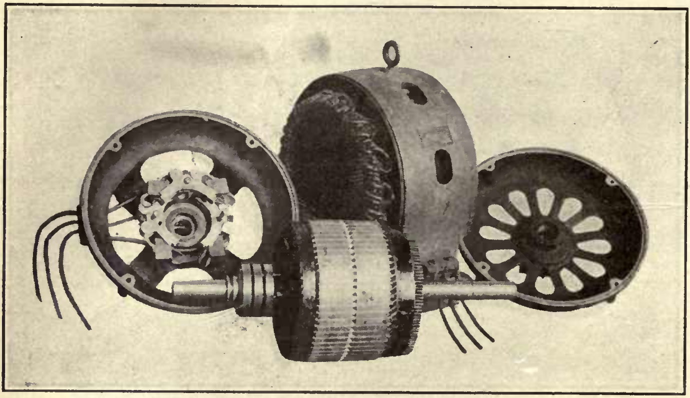

FIGURE 207.—A LARGE A. C. POWER MOTOR DISASSEMBLED TO SHOW DIFFERENT PARTS. (SLIP RING TYPE.)

The armature must turn fast enough to generate a *C. E. M. F.* almost equal to the *applied E. M. F.* If the field is weak the armature must burn fast, but if it is strong

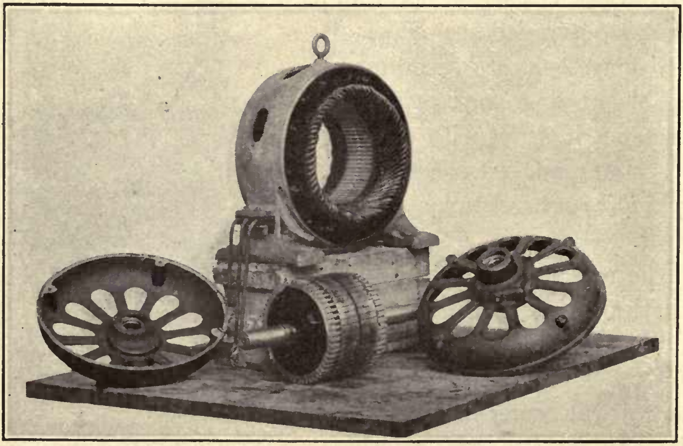

FIGURE 208.—ANOTHER LARGE A. C. POWER MOTOR DISASSEMBLED. (SQUIRREL CAGE TYPE.)

then the armature need only turn slowly, to generate this necessary *C. E. M. F.*

Therefore, since *adding* resistance in series with the field makes the field *weaker*, it causes the motor to speed up, and since *taking out* resistance in series with the field makes the field *stronger*, it causes the motor to slow down.

This motor is used where it can start without load, and can then have the load thrown on gradually, as in the case of motors in a machine-room.

230. Small Motors. — If the motor is small enough, it may be put directly on the line, without a starting-box. In this case the armature is so light in weight that it can start to full speed before the coils have time to burn out.

231. Specific Uses of A. C. and D. C. Motors in the Home. — Motors for either A. C. or D. C. circuits are often used for the following purposes:

1. Electric fans.
2. Sewing machines.
3. Washing machines.
4. Kitchen motors.
5. Vacuum cleaners.
6. Hair driers.

Name any other uses you know.

CHAPTER XVIII

INDUCTION

232. Permanent Magnet in a Coil of Wire. — *Induction is the producing of an electrical pressure (E. M. F.) by means of a conductor cutting magnetic lines of force.* This is not a new idea, but is one which we have been using all through the subject of Electricity. We spoke of it when we studied the simple generator.

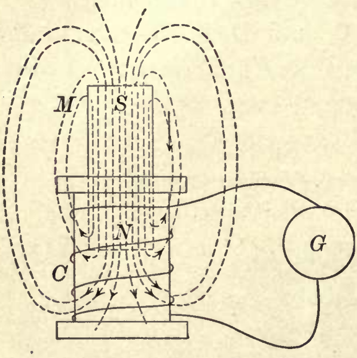

Figure 209. — A Permanent Magnet Being Thrust into a Coil of Wire.

In the simple generator the conductor *moved* and cut the lines of force, which remained *stationary*. This action may be reversed, — the conductor remaining stationary and the field moving, — and the result will be the same.

Figure 209 shows a permanent magnet (M) thrust into a coil of wire (C), the ends of the coil being connected through the galvanometer (G). When this is done, the galvanometer will deflect, showing that a current passes through the coil. The lines of force come out of a N-pole and go around and into a S-pole. When the magnet is thrust downward, these lines are cut by the wire in the coil.

If the magnet were pulled out, the lines of force would be cut in the opposite direction, and the galvanometer would deflect in the opposite direction, showing that the current is reversed.

Then, to thrust a N-pole in and pull it out immediately produces an A. C. current in the coil.

Just the reverse action takes place when a S-pole is thrust in and pulled out, since the lines of force are reversed. That is, to pull a S-pole out is the same as to thrust a N-pole in, and to thrust a S-pole in is the same as to pull a N-pole out.

233. An Electro-magnet in a Coil of Wire. — Figure 209 shows a coil of wire with a permanent magnet thrust into it. Figure 210 shows the same coil of wire, but instead of a permanent magnet an electromagnet has been used. The effect is exactly the same as before.

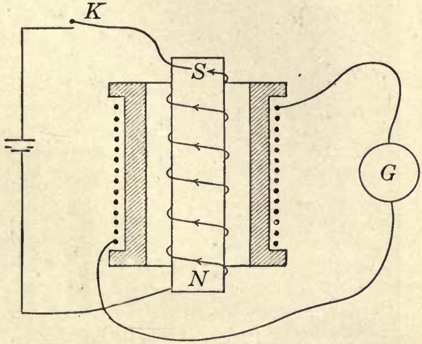

FIGURE 210. — AN ELECTRO-MAGNET IN A COIL OF WIRE.

Now, if instead of thrusting in and pulling out this electromagnet, the core with the wire around it is placed *inside* the coil of wire, and the key (*K*) is pressed and released, the same effect is obtained.

While the key is open, the core is not a magnet; then when it is pressed, the core becomes a magnet, giving the same effect as thrusting a magnet in. Again, when the key is released, the core loses its magnetism, and the result is the same as when the magnet is pulled out.

Thus we see that if two coils are placed so that one is inside the other, and a current is *made* in one, a current is *induced* in the other. Also, if a current is stopped in one, a current is *induced* in the other, in the *opposite* direction.

The coil in which the current is made or stopped is called the *primary*, while the coil in which the current is induced is called the *secondary*.

234. Mutual and Self-induction. — The above case is called *mutual induction*. It is the producing of a current in one wire by the effect of a current in another.

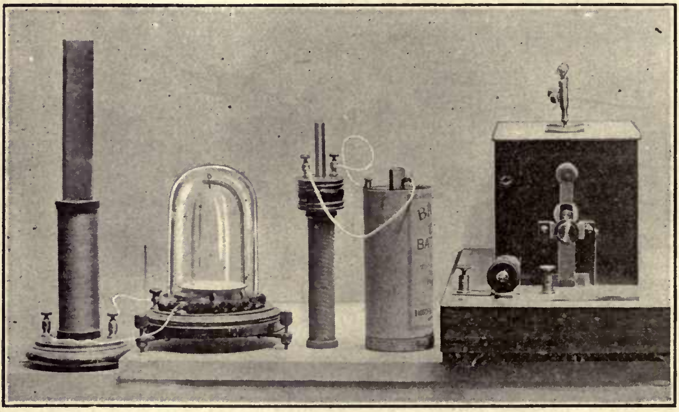

FIGURE 211. — INDUCTION APPARATUS.

Self-induction has to do with but *one* wire.

It takes time and energy to start an automobile. The tendency of the automobile to hold back, or stay where it is, is called *inertia*. *The tendency for a current not to flow when it is being started, and to keep on flowing when it is being stopped, is called* **self-induction**.

Self-induction always takes place when a current is changed (made larger or smaller) in a circuit. It acts in the opposite direction to the change.

235. The Induction Coil. — The induction coil or "spark-coil," is used to increase the pressure in a D. C. circuit so that a spark will jump across a gap.

The wiring diagram of an induction coil is shown in Figure 212.

A coil of heavy wire (p) is wound on a soft iron core, with a few turns. Around this is wound a coil of fine wire, with many turns. The coil of heavy wire is called the *primary*, and is connected in series with a push button (P), a battery (B), and a vibrator (V). The fine-wire coil is called the *secondary*, and ends at opposite sides of a spark gap. *A condenser* (C) is placed across the gap made by the vibrator.

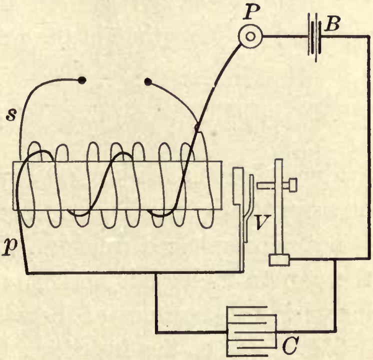

FIGURE 212. — WIRING DIAGRAM OF THE INDUCTION COIL.

A *condenser* is a storage tank for electricity. It is usually made up of layers of tinfoil insulated from one another by mica or other insulating material, alternate layers being connected together. Positive electricity flows in on one side, and negative on the other. The more leaves or layers, the more it will hold.

In the primary of the induction coil the action is the same as in the door bell, the vibrator flying backward and forward, making and breaking the current. Whenever the current changes in the primary, a current is *induced* in the secondary by *mutual induction.*

Since there are several times as many turns in the secondary as there are in the primary, the voltage of the secondary will be just that many times as great as in the primary.

To explain: Suppose the primary has 10 turns and the secondary 1000 turns, and that the primary produces a field of a certain strength. Now, for every turn on the primary there are $\frac{1000}{10}$, or 100, turns on the secondary. Hence, the secondary cuts 100 times as many lines of force as the primary. Since the voltage depends upon the number of lines cut per second, the voltage in the secondary will be 100 times that in the primary, or

$$\frac{\textit{voltage of secondary}}{\textit{voltage of primary}} = \frac{\textit{turns of secondary}}{\textit{turns of primary}}$$

Since there is self-induction wherever a current is started or stopped, the making and breaking of the primary circuit is not accomplished quickly. The condenser is put in over the gap to make this action take place more quickly, thus increasing the voltage of the spark.

236. Uses of the Induction Coil. — The induction coil is used in igniting the gas in gas engines. It is also used for medical purposes.

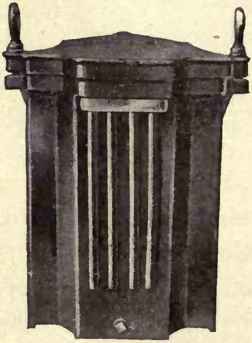

FIGURE 213. — A LOW VOLTAGE TRANSFORMER.

237. The Transformer. — The induction coil was used on D. C., the vibrator changing the current in the primary. Now if A. C. is used, a vibrator need not be put in, but the primary may be wound about a soft iron without any mechanism to regulate it. The alternation of the current takes the place of the *make* and *break* of the induction coil.

Such an arrangement is called a *transformer*. It consists merely of two coils wound on a soft iron core. One coil is made of fine wire with many turns, while the other is made of heavy wire with few turns.

As in the induction coil, the voltages of the coils depend upon the ratio of the number of turns. The coil which has the current put into it is called the *primary,* while the one in which the pressure is induced is called the *secondary.*

The commercial transformer has four coils; two with fine wire, and two with coarse wire, wound on the same common core of laminated soft iron. The ratio of turns in these coils is 10 to 1. That is, for every turn on a coarse-wire coil there are 10 turns on a fine-wire coil.

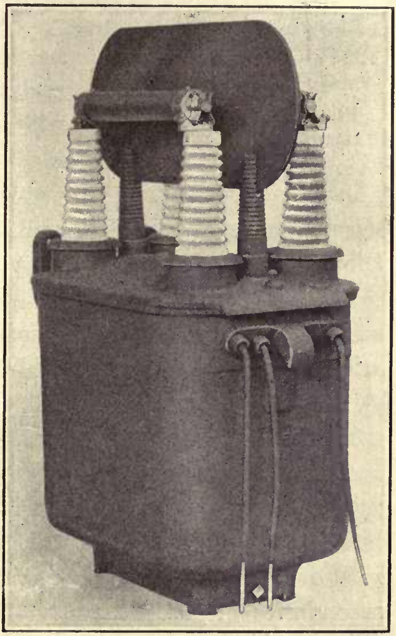

FIGURE 214. — A HIGH TENSION (VOLTAGE) TRANSFORMER.

By connecting the coils in different combinations different voltages may be obtained.

With a 110-volt primary line six voltages may be obtained with a commercial transformer — three by using the coarse-wire coils as primary, and three by using fine-wire coils as primary.

238. Coarse-wire Primary. — 1. If the primaries are connected in parallel, and the secondaries in series, the voltage will be $\frac{20}{1} \times 110 = 2200$. (Figure 215.)

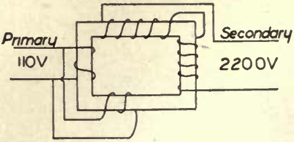

FIGURE 215. — 110 VOLTS TRANSFORMED TO 2200 VOLTS.

2. If the primaries are connected in parallel and the secondaries in parallel, the voltage will be $\frac{10}{1} \times 110 = 1100$. (Figure 216.)

3. If the primaries are connected in series and the secondaries in parallel, the voltage will be $\frac{10}{2} \times 110 = 550$. (Figure 217.)

239. Fine-wire Primary. — 1. If the primaries are connected in parallel and the secondaries in series, the voltage will be $\frac{2}{10} \times 110 = 22$. (Figure 218.)

2. If the primaries are connected in parallel and the secondaries in parallel, the voltage will be $\frac{1}{10} \times 110 = 11$. (Figure 219.)

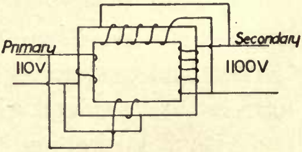

FIGURE 216. — 110 VOLTS TRANSFORMED TO 1100 VOLTS.

3. If the primaries are connected in series and the secondaries in parallel, the voltage will be $\frac{1}{20} \times 110 = 5\frac{1}{2}$. (Figure 220.)

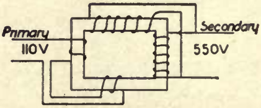

FIGURE 217. — 110 VOLTS TRANSFORMED TO 550 VOLTS.

240. Uses and Advantages of the Transformer. — First of all, you must remember that transformers can be used only on A. C.

They are used for stepping the voltage up or down. Your house circuit is not in electrical connection with the power station, but comes from a transformer near the house, where the voltage has been stepped down from 2300 volts to 110 volts. In fact, wherever power is to be delivered some distance it is sent out at *high voltage,* and then stepped down so that it can be used.

The transformer has many advantages, but the four principal ones are these:

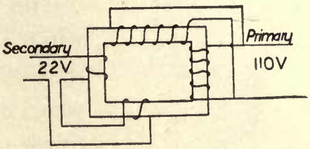

FIGURE 218. — 110 VOLTS TRANSFORMED TO 22 VOLTS.

1. *It makes it possible to get any voltage you like from any voltage delivered.*

2. *It saves cost of wire.* Since power = $E \cdot I$, if the power is sent out at a large voltage, the current may be small, and since it is the current that heats a wire, the wire may be small when the current is small.

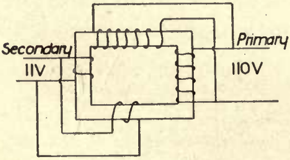

FIGURE 219. — 110 VOLTS TRANSFORMED TO 11 VOLTS.

3. *It saves line drop, or fall of voltage.* The fall of voltage along a line is the *resistance of the line* × *the current flowing.* We saw how the current could be made smaller with the transformer, and so *line drop* is cut down.

4. *It saves line loss.* Line loss is power lost in the line, and is *the line drop* × *current.* Since the transformer makes it possible to reduce both the line drop and the current, it makes it possible to reduce the line loss.

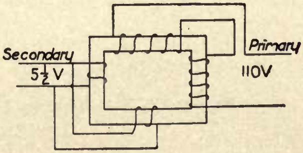

FIGURE 220. — 110 VOLTS TRANSFORMED TO 5½ VOLTS.

On account of the advantages just named nearly all transmission lines are of high tension (voltage). Being of high voltage, they are dangerous, and so are usually put up on strong towers, very well insulated, the wires themselves being bare.

241. The Three-phase System. — Heretofore we have always considered an electric circuit as having two lines, one line out and one line back.

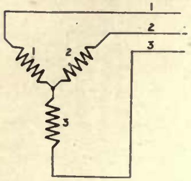

FIGURE 221. — WIRING DIAGRAM OF A 3-PHASE GENERATOR.

The modern system of delivery is what is called the "three-phase" system. It consists of three wires instead of two, and carries three times as much power as a two-line system.

The generator for three-phase current is so arranged that the current goes out on one of the wires and comes back on the other two, or goes out on two and comes back on one.

For example, at one instant the current is flowing out on line *No.* 1 (Figure 221), and at the same time is coming back on *No.* 2 and *No.* 3; an instant later it will go out on *No.* 2, and come back on *No.* 1 and *No.* 3, *etc.*

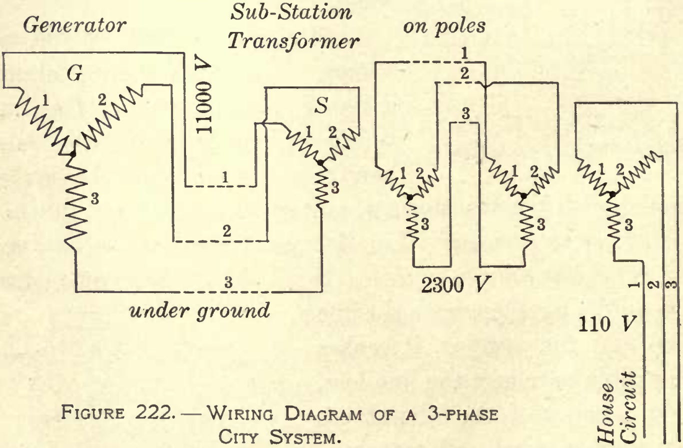

FIGURE 222. — WIRING DIAGRAM OF A 3-PHASE CITY SYSTEM.

This is the system used in Cleveland, Ohio, by the Illuminating Company.

242. The Wiring Diagram of a City System. — Figure 222 shows the general wiring diagram of a city using a 3-phase current. The electricity is generated at the generator (*G*) at 11,000 volts, and is sent out to the sub-stations (*S*) in conduits under ground. Here it runs through transformers and is stepped down to 2300 volts. This is carried out on poles to the locality in which it is to be used. Here it is stepped down to 110 volts by transformers placed on the poles. This 110-volt line is carried into the houses.

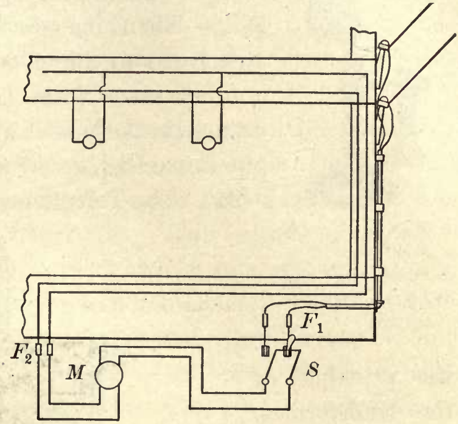

FIGURE 223. — WIRING DIAGRAM OF A HOUSE CIRCUIT.

243. Wiring Diagram of House Circuit. — The current is brought into the house on two insulated wires at 110 volts.

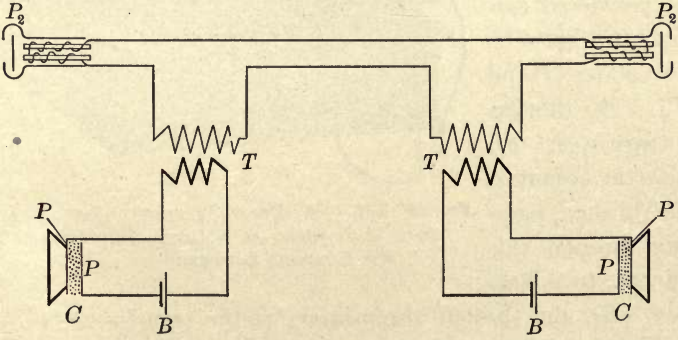

FIGURE 224. — WIRING DIAGRAM OF A SIMPLE TELEPHONE CIRCUIT.

A city ordinance usually requires that all new wiring must enter the house at the basement. Just after it enters the house it passes through fuses. (F_1, Figure 223.) Then it goes through the service switch (S) to the meter (M); then through another set of fuses (F_2); and then to the fixtures in the house; all the appliances being put in parallel, *across the line.*

FIGURE 225. — A PORTABLE TELEPHONE RECEIVER AND TRANSMITTER.

244. The Telephone. — The telephone uses the principle of the transformer. Figure 224 shows a diagram of the simple Bell telephone.

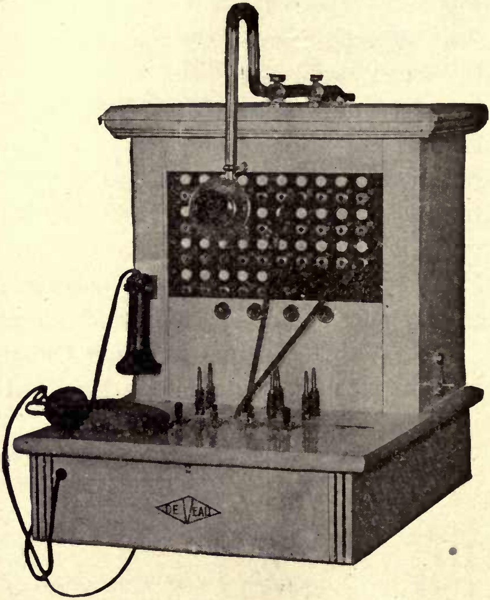

FIGURE 226 — A DESK TELEPHONE SWITCHBOARD SUCH AS IS USED AS A LOCAL SWITCHBOARD BY A LARGE BUSINESS CONCERN.

In the transmitter is a layer of powdered carbon (C) between two plates (P and P). By this arrangement an electric circuit is established, passing through this carbon to a battery (B), and through the primary of the transformer (T).

The secondary circuit consists of the following parts, all being put in series: (*a*) the secondary coil of the local transformer, (*b*) the secondary coil of the transformer at the other station, (*c*) the coil of wire about the permanent magnet at the local station, (*d*) the similar coil about the permanent magnet at the other station, and (*e*) the connecting line wires.

When the speaker talks into the transmitter, the little plate P alternately squeezes and releases the carbon, thus reducing and increasing its *resistance.* This causes the current in the primary to fluctuate. This induces an alternating current in the secondary, which in turn strengthens and weakens the permanent horseshoe magnets. As these magnets are strengthened and weakened, they first pull, and then release, the steel plate (P_2) in the receiver, causing it to flip backward and forward. This plate (P_2) then reproduces the sound that enters the transmitter.

CHAPTER XIX

CHEMICAL RELATION OF AN ELECTRICAL CURRENT

245. The Electrolytic Cell. — Sometimes liquids instead of solids are used as conductors of electricity. For instance, a salt solution will conduct electricity. When the current passes through a solution like this, a chemical change takes place which is quite different from what happens when a substance like mercury conducts electricity.

The solution, with the points of contact, is called an *electrolytic cell.*

246. Chemical Action in an Electrolytic Cell. — When a solution is made, part of its molecules break up into parts or *ions*, and are said to *ionize*. Before this can be understood a few terms must be learned.

An *atom* is the smallest known part of an element which will enter into a chemical change. For example, a copper atom is the smallest known part of the element copper which will enter into a chemical change. We let the symbol Cu stand for it.

A *radical* is a group of atoms acting as a single atom in a given chemical change. For example, in $CuSO_4$ the SO_4 is called a radical, and does not break up in a given chemical change.

An *ion* is an atom or a radical, with an electrical charge. For example, a Cu atom with a charge of electricity is called a *copper ion*, and is written Cu^+. Also, the radical SO_4

with a charge of electricity becomes an ion, and is called a *sulphate ion* and is written SO_4^-. Positive ions carry positive charges, and negative ions carry negative charges. The same kind of atoms or radicals always carry the same kind of charge.

Thus, when we say a solution ionizes, we mean it breaks up into atoms and radicals carrying electrical charges.

When an electrical current passes through a solution, the positive ions are made to flow *with* the current, while the negative ions flow in the other direction. Also, more of the solution ionizes. This is the way a solution conducts the current.

247. Parts of an Electrolytic Cell. — The parts of an electrolytic cell are (1) the solution, which is called the *electrolyte;* (2) the contact, or pole where the current comes in, called the *anode;* and (3) the contact, or pole where the current goes out, called the *cathode.*

248. The Copper Sulphate ($CuSO_4$) Electrolytic Cell. — A solution of $CuSo_4$, with a copper anode and any other conductor for a cathode, will make an electrolytic cell. (Figure 227.) The action is as follows:

When the current is turned on, the $CuSo_4$ ionizes (some of it is already ionized) into Cu^+ and SO_4^-. The Cu^+ passes over to the cathode and gives up its charge, and places the *Cu* on the cathode. The SO_4 passes over to the anode, unites with an atom of the copper plate, — with the aid of the positive charge coming through

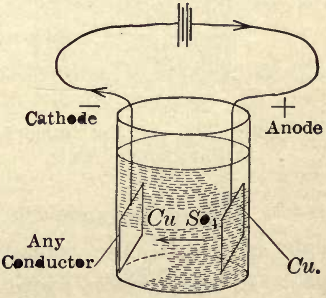

FIGURE 227. — A COPPER SULPHATE ELECTROLYTIC CELL.

the wire, — and forms new $CuSO_4$. As this action continues, the cathode becomes plated with copper, and the anode is eaten away.

This action can be expressed by the three following equations:

$$\begin{aligned} &CuSO_4 \longrightarrow Cu^+ + SO_4^- \\ &Cu^+ \longrightarrow Cu + (+) \\ &SO_4^- + Cu + (+) \longrightarrow CuSO_4 \end{aligned}$$

249. The Sulphuric Acid (H_2SO_4) Electrolytic Cell. — A solution of H_2SO_4 with a cathode and anode of platinum will form an electrolytic cell. (Figure 228.)

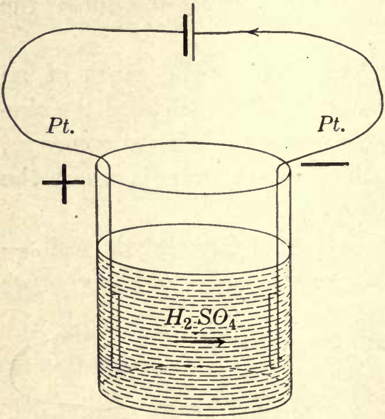

FIGURE 228. — A SULPHURIC ACID ELECTROLYTIC CELL.

The action is as follows:

The H_2SO_4 ionizes into $2H_2^+$ and SO_4^-. The $2H_2^+$ passes over to the cathode and there deposits its charge, the free hydrogen bubbling off as a gas. The SO_4^- passes over to the anode, but cannot attack the platinum, so it unites with a molecule of water (H_2O), with the aid of the positive charge (+) coming through the wire, and forms a new molecule of H_2SO_4, the remaining oxygen bubbling off as a gas. As this action continues, the two plates remain the same, but the solution becomes concentrated, as H_2O is taken off in its two constituent gases.

This action may be expressed by the three following equations:

$$
\begin{aligned}
&H_2SO_4 \longrightarrow 2\,H_2^+ + SO_4^-\\
&H_2^+ \longrightarrow 2\,H + (+)\\
&SO_4^- + H_2O + (+) \longrightarrow H_2SO_4 + O
\end{aligned}
$$

There are many different electrolytic cells but the action in all is similar to that in the two just studied.

250. Electro-plating. — The electrolytic cell is used in plating. A solution containing a salt of the metal to be plated on the object is used as an electrolyte. The object to be plated is used as a cathode, and the anode is of the same material as the metal to be plated on the object. The action is exactly the same as in the case studied under the $CuSO_4$ electrolytic cell.

Many precautions are required to make plating successful. The solution must be of just the right strength, the object to be plated must be perfectly clean, and the rate of plating, or the size of the plating current, must be just right.

It is by this process that nearly all modern plating is done. Name some things that are silver-plated. Some that are nickel-plated, some that are gold-plated.

251. Electro-typing. — Electro-typing is another of the useful things done by means of the electrolytic cell. All the cuts in books, magazines, and newspapers as well as the reading matter of most of our books are made by electrotyping. (The reading matter of most newspapers is not electro-typed.)

If the thing to be electrotyped is a page of printed matter, the type is first set up. Then an impression is made in wax. This impression is next sprinkled with graphite to make it a smooth conducting surface. Then this form is used as the cathode in a plating cell. Copper about the thickness of paper is plated on the graphite surface. This is then backed with type-metal to make it strong, and the wax is melted off. This plate can then be used as often as desired, and is easily stored away. The type used at the beginning can be used over and over again.

CHAPTER XX

BATTERIES

252. The Simple Voltaic Cell. — We have learned that an electrical pressure is generated whenever lines of force are cut by a conductor. Here are three other known ways by which an electrical pressure may be produced:

1. By chemical action.
2. By certain kinds of friction.
3. By heating two metals in contact.

If a glass jar has a solution of common salt put into it, and a zinc strip and copper strip be put into the solution and joined together by a conductor, an electrical current will flow. The jar of salt water with its copper and zinc strips is called a *voltaic cell,* for it *generates* an electrical pressure. The pressure is set up by the chemical action which takes place in the cell.

Care should be taken not to confuse the terms " voltaic cell " and " electrolytic cell." The latter is merely a *conductor* of electricity, while the former *produces* an electrical pressure.

253. The H_2SO_4 Voltaic Cell. — There are several kinds of voltaic cells. We just learned that salt water with copper and zinc strips for " electrodes " forms a voltaic cell. So, also, does dilute H_2SO_4 with copper and zinc electrodes.

Let us note the chemical action that takes place in the H_2SO_4 voltaic cell. (Figure 229.)

As soon as the circuit is closed, the ionized H_2SO_4 separates, the H_2 going to the Cu electrode and giving up its charge, the 2 H being given off as a gas. The SO_4 goes to the Zn plate, receives the positive charge coming around the wire, and unites with the Zn to form $ZnSO_4$ (zinc sulphate).

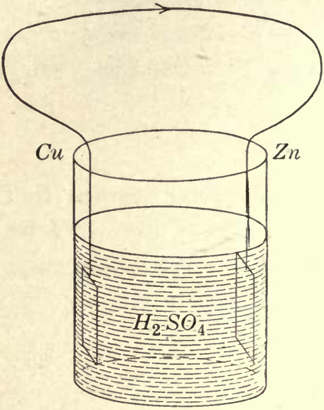

FIGURE 229. — A SULPHURIC ACID VOLTAIC CELL.

This action may be shown by the three following equations:

$$H_2SO_4 \longrightarrow H_2^+ + SO_4^-$$
$$H_2^+ \longrightarrow 2\,H + (+)$$
$$SO_4^- + Zn + (+) \longrightarrow ZnSO_4$$

Thus we see that an electrical current is sent through the wire, that the H_2SO_4 is used up, that $ZnSO_4$ is made in its place, and that the Zn strip is eaten up.

254. Polarization. — It was seen above that hydrogen gas is given off at the copper plate. In all cells where this is done there is a tendency for these hydrogen bubbles to stick to the plate, and thus insulate it. This is called *polarization.*

255. Open-circuit Cells. — Cells which polarize cannot be run for long periods, because the positive plate becomes insulated by the hydrogen. Therefore these cells are called "open-circuit cells," because the circuit on which they are placed must remain open most of the time and can be closed for only short periods.

Name some uses of open-circuit cells.

256. The Wet Salammoniac Cell. — An open-circuit cell may be made by placing a handful of ammonium chloride

(NH_4Cl) in a quart jar filled with water, using a strip of carbon for a positive electrode and a zinc strip for a negative electrode. This cell is often used for doorbells.

257. The Dry Cell. — The dry cell has the same chemical action as the wet NH_4Cl cell, but it is constructed differently, so that it may be handled much easier.

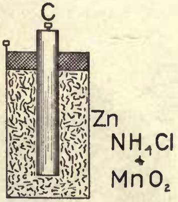

FIGURE 230. — CROSS SECTION OF A SIMPLE DRY CELL.

Figure 230 shows a cross section of this cell. The outside, or case, is zinc, and acts as the negative electrode. The center portion (C) is a stick of carbon, which is the positive electrode. Packed in around this carbon stick is a paste of NH_4Cl and manganese dioxide (MnO_2). The NH_4Cl is the active portion, and the manganese dioxide is put in to retard polarization. This is an open-circuit cell.

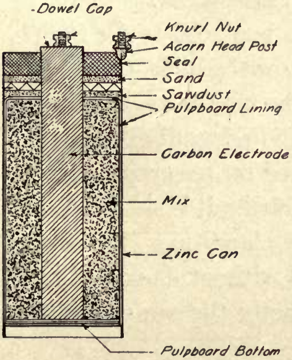

FIGURE 231. — CROSS SECTION OF A COMMERCIAL DRY CELL, AS IT IS NOW MANUFACTURED.

The top shaded portion is tar, or wax, used to seal the cell so that the moisture will not dry out. This cell gives about 1.4 volts, and, when new, will give as high as 30 amperes on short circuit.

Name some uses of the dry cell.

258. The Addwater Cell. — The Addwater cell is an open-circuit cell, the construction of which is kept secret by the manufacturers. Its advantage over the ordinary dry cell is the fact it will last longer, as it has a well to be filled with water, thus keeping it from drying out.

259. Closed-circuit Cells. — In the case of some voltaic cells there is no hydrogen given off in the form of a gas, and so these cells do not polarize. Keeping the circuit closed for a long period does not harm them, and they are called "closed-circuit cells."

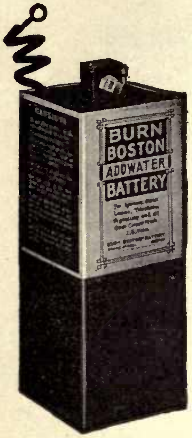

FIGURE 232. — THE ADDWATER CELL, WHICH IS A SPECIAL KIND OF DRY CELL.

Name some uses for closed-circuit cells.

260. The Gravity Cell. — The gravity cell consists of two solutions placed in a glass jar with copper and zinc electrodes. These two solutions are concentrated $CuSO_4$ and dilute $ZnSO_4$ (5–1). The $CuSO_4$ is placed in the bottom, and the $ZnSO_4$ on top. They keep these relative positions on account of their difference in density, hence the name "gravity cell."

The copper plate is placed in the $CuSO_4$, and the zinc plate, or "crowfoot," is hung in the $ZnSO_4$. The circuit must be kept closed, or the two liquids will diffuse, thus spoiling the cell. These cells are used on telegraph lines.

261. The Daniell Cell. — The Daniell cell is similar to the gravity cell, except that the $ZnSO_4$ is placed in a clay porous cup so that the cell may be handled without danger of mixing the solutions. The action is exactly the same as in the gravity cell.

262. Secondary or Storage-cells. — The voltaic cells we have been studying are capable of giving an electrical pressure as soon as they are set up, and are therefore called *primary cells.* It has been found that cells may be made which will not at first give an electrical pressure, but which will do so if "charged." These cells are called "*secondary cells*" or "*storage-cells.*"

263. The Lead Wet Storage-cell. — A storage-cell may be made by using two *lead* plates for electrodes and dilute H_2SO_4 for an electrolyte. (Figure 233.)

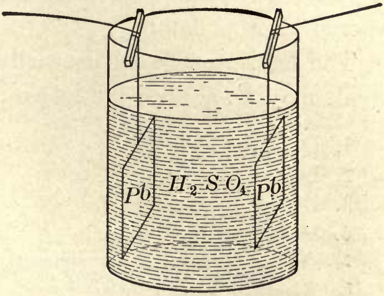

FIGURE 233. — A DIAGRAM OF A WET LEAD STORAGE BATTERY.

When first set up, this cell will not give a pressure, but if a D. C. current is allowed to flow through it for a time it is said to become "charged," and will then give an electrical pressure.

The charging current causes a chemical action to take place within the cell, thus storing up *chemical energy*. No *electricity* is stored in the cell. Then, when the cell is used to give pressure, the current flows in the opposite direction, at the expense of the chemical energy stored in it. When this energy is exhausted, the cell must be recharged.

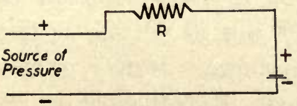

FIGURE 234. — WIRING DIAGRAM OF A STORAGE BATTERY CHARGING CIRCUIT.

FIGURE 235. — A COMMERCIAL LEAD STORAGE BATTERY.

To charge the cell, a D. C. must be used, and the + pole of the charging circuit must be connected to the + pole of the cell. (Figure 234.)

If A. C. is used, it must first be *rectified*, that is, changed into D. C. by a motor generator, a rotary convertor, or a mercury vapor lamp.

The lead storage-cell is easily injured, so a few precautions may be appropriately named:

1. D. C. current must be used for charging.
2. Do not overcharge.
3. Do not short circuit.
4. Do not charge too fast.
5. Do not let it remain uncharged.
6. Keep it filled with *pure* water.

The lead storage battery is used for many things. Some of these uses are:

1. To run electric motor cars.
2. To start motors and to light cars.
3. To light houses in the country.
4. For plating.

The lead storage-cell gives about 2 volts per cell, regardless of the size of the cell.

264. The Dry Lead Storage-cell. — There has just recently been put on the market a dry lead storage-cell (Figure 236), but as yet, its success has not been shown. It may, or may not, be good. Its principle is exactly the same as the wet lead cell, but instead of the acid being in a free state, it is absorbed by a compound, thus forming a "dry" cell. The electrodes are lead plates wound

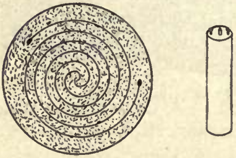

FIGURE 236. — DIAGRAM OF A DRY LEAD STORAGE BATTERY.

in concentric spirals, thus giving a large active area. The absorbing compound is pressed in between the plates with such force that the active material on the plates cannot come out.

If this cell proves to be good, it will be a great step in storage battery construction, for free acid is a dangerous thing to handle.

265. The Edison Storage-cell. — Thomas A. Edison has had an altogether different storage-cell on the market for some time. This cell has potassium hydroxide (KOH) for an electrolyte, and patented nickel and steel electrodes. The container is a pressed-steel box, so that it is almost indestructible. The Edison cell does not need the care that a lead cell does, and can be subjected to much more

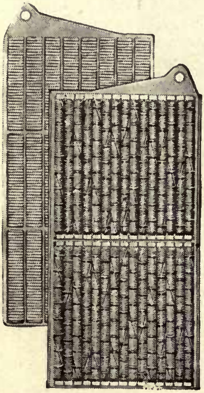

Figure 238. — The Positive and Negative Plates of an Edison Cell.

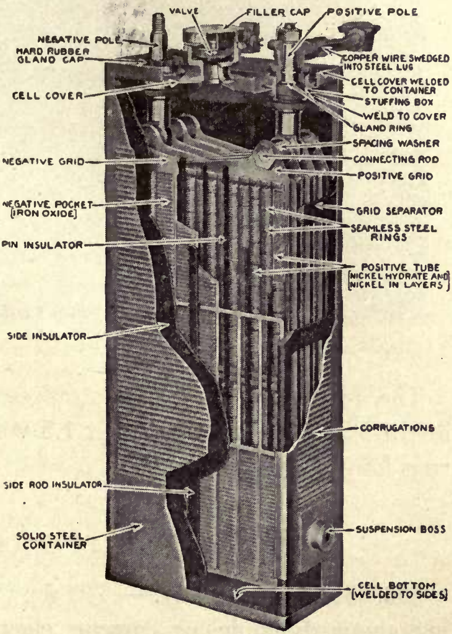

Figure 237. — Dissected View of an Edison Storage Battery Cell.

rough handling, without injury. A short circuit does not permanently harm it, if it is immediately recharged.

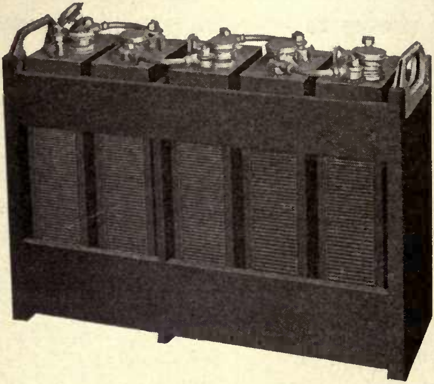

FIGURE 239. — A WOODEN TRAY CONTAINING 5 EDISON CELLS.

The voltage of the Edison storage-cell is lower than that of the lead cell, it being about 1.5 volts; and its efficiency runs lower than the lead cells.

STATIC ELECTRICITY

266. Static Electricity. — Till now we have been studying about dynamic or current electricity. But there is another kind called *static electricity*.

There are many applications of this form of electricity, such as lightning, wireless telegraphy, and medical uses. When we scuff across a thick rug in a cold room and then touch a metal door-knob or gas-fixture, we get a slight shock due to static electricity.

Although the applications of static electricity are spectacular and interesting, it has not the widespread practical

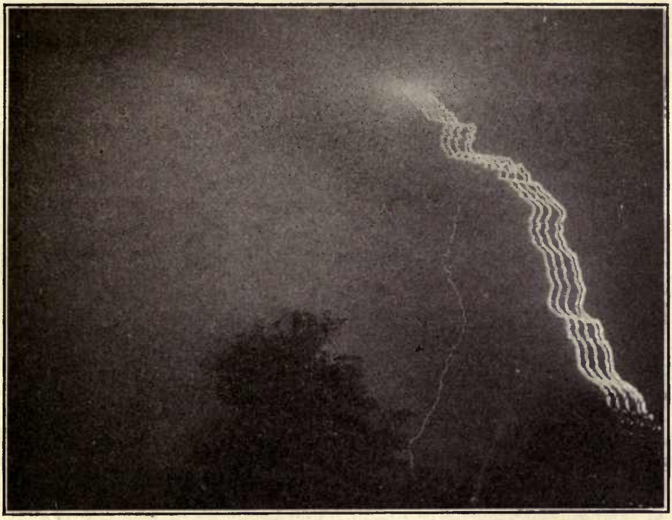

Figure 240. — An Actual Photograph of a Stroke of Lightning Taken on the Shore of Lake Michigan.

value of current electricity. For this reason a complete treatment of it is not embodied in this book.

Review Problems

1. Discuss the field about a magnet.

2. Distinguish between a magnetized piece of iron and one which is not magnetized.

3. Why is magnetism studied before electricity?

4. How may an electrical pressure be generated? What determines its amount and its direction?

5. Discuss pressure, current, and resistance.

6. Distinguish between A. C. and D. C.

7. How is an A. C. made D. C.?

8. Describe the space about a wire carrying a current.

9. What determines the poles of an electro-magnet?

10. Name ten applications of the electro-magnet.

11. How does electricity produce heat?

12. Name five electrical quantities to be measured, the unit used for each, and the letter used to denote each.

13. If a door bell has 180 ohms resistance, what current will it take if 6 volts are applied to it?

14. What is the cost of running a motor for 2 hours, if it takes 3 amperes on 110 volts, the cost of electricity being 9¢ per Kw.-hr.?

15. How long would a starting-battery last if it contained 600 watt-hours and gave a pressure of 6 volts at a 300-ampere discharging rate?

16. Compare the cost of running four 25-watt lamps to that of three 40-watt lamps.

17. How much would you save on your electricity bill if you had an attachment like the " dim-a-lite," which would throw in an additional 100 ohms to the 340 ohms if the lamp were to burn 8 hours on a 110-volt circuit, and cost 9¢ per Kw.-hr.?

18. In problem 17 would the lamp be as bright with the extra 100 ohms in the circuit?

19. What heats an electrical flat-iron?

20. How does electricity produce motion?

21. Explain how the ammeter measures current.

22. Show where a voltmeter and an ammeter should go in a circuit.

23. What is the difference between A. C. and D. C. meters?

24. Discuss the essential parts of a watt-hour meter.

25. What is C. E. M. F.?

26. Tell briefly the difference between a series and a shunt motor.

27. What is induction?

28. Discuss mutual- and self-induction.

29. How could you get 6 volts from a 120-volt A. C. line?

30. If the two coils of a transformer have their turns in the ratio of 3 and 24, what voltages could you get from a 110-volt A. C. line?

31. What is the advantage of the 3-phase system?

32. Discuss the wiring diagram of a house.

33. What is the difference between an electrolytic cell and a voltaic cell?

34. Explain how silverware is plated.

35. Why is a dry-cell called an " open-circuit cell "?

36. Give some applications of static electricity.

CHAPTER XXI

MECHANICS OF SOLIDS

267. Units of Measurement. — The things with which physics deals are very definite, and so require definite units to measure them. For example, the houses we live in are of definite *sizes*, the food we eat has a certain *weight*, and you go to class for a definite length of *time*. All these quantities are definite, and in order to express them we must have definite units.

This is not a new thing, for we have been using units all through this course, but it is advisable to study them for their own sake.

268. The English System. — There are two great systems of measurement — the English and the Metric. There is no necessity for two systems, but we have them, and people will continue to use both for many years to come.

There are other things to be measured, but the three principal ones are *space*, *mass* (incorrectly called *weight*), and *time*.

Under space, come *length*, *area*, and *volume*. The English unit of length is the *foot*. Other units are derived from this; the *yard* = 3 ft.; the *inch* = $\frac{1}{12}$ ft.; the *mile* = 5280 ft.

The unit *foot* is made definite by the fact that the original is kept in London. Copies of it are made and used as standards of measurement. Our standard is kept at Washington.

The units of area and volume are derived from the units of length. Thus the *square foot* is an area which is one foot on a side; the *cubic foot* is a cube which is one foot on each edge. (Figure 241.)

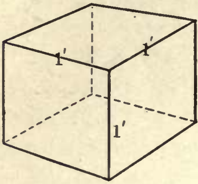

Figure 241. — A Cubic Foot.

Other units, such as *square yard, cubic yard, square inch, cubic inch, etc.*, have similar meanings.

The unit of mass is the *pound* (lb.), and it denotes a certain amount of matter determined by a standard kept in the same way as the standard foot. Other units are derived from it, such as the *ounce* (oz.) = $\frac{1}{16}$ lb.; the *ton* (T.) = 2000 lb.; etc.

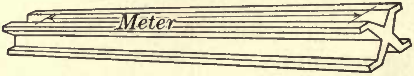

Figure 242. — The Standard Meter.

The unit of time is the *second* (sec.); it is based on the time it takes the earth to make one rotation on its axis. The second is $\frac{1}{86400}$ of that time. The other units derived from it are the *minute* (min.) = 60 sec.; the *hour* (hr.) = 60 min.; the *day* = 24 hr.; the *year* = $365\frac{1}{4}$ days.

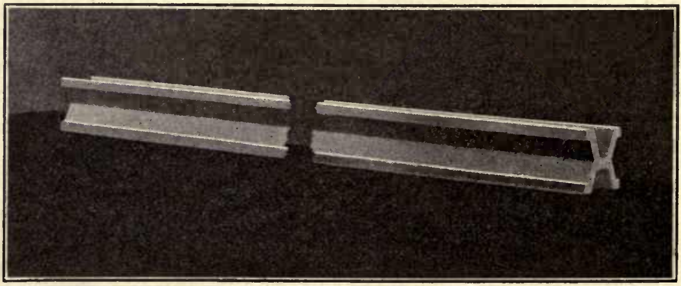

Figure 243. — United States National Prototype Meter Bar, Bureau of Standards, Washington, D. C.

269. The Metric System. — The same quantities can be measured in the metric system, but the units are different. The unit of length is the *meter* (m.); and it is defined as the distance between two scratches made on a platinum bar kept at Paris. (Figure 242.)

Table of Lengths

10 millimeters (mm.) = 1 centimeter (cm.)
100 cm. = 1 meter (m.)
1000 m. = 1 kilometer (km.)

The metric unit of mass is the *gram* (gm.), and it is $\frac{1}{1000}$ part of a piece of brass kept in Paris along with the standard meter. This piece of brass was so made that it has the same mass as 1000 c.c. of pure water at 4° C. That makes the gram equal to the mass of 1 c.c. of pure water at 4° C.

Other units are given in the table.

Table of Masses

1000 milligrams (mg.) = 1 gram (gm.)
1000 gm. = 1 kilogram (kg.)

The metric unit of time is the *second*. It is identical with that of the English unit.

270. The Two Systems Compared. — Just a glance at the two systems is sufficient to show that the metric is much the simpler.

All the derived units in the metric system are multiples of *ten*. For example, 10 mm. = 1 cm., 100 cm. = 1 m., 1000 m. = 1 km., etc. This makes it easy to remember and, at the same time, easy to change from one unit to another. All that is necessary is to move the decimal point either to the right or left. For example:

1.273 m. = 127.3 cm.
467.8 cm. = 4.678 m.
3.642 kg. = 3642 gm.

In the English system this is not true. There is no regularity whatever. This makes it hard to change from one unit to another. For example:

15 ft. = 15×12 = 180 in.
231 in. = $\frac{231}{12}$ = $19\frac{1}{4}$ ft.
3 lb. = 3×16 = 48 oz.
90 oz. = $\frac{90}{16}$ = $5\frac{5}{8}$ lb.

271. Relation between the Two Systems. — So long as there are two systems in use, we shall at times be obliged to change readings in one to readings in the other. For this reason we need a table of equivalents. The fact that the two systems are entirely independent makes these equivalents irregular and burdensome.

Table of Equivalents

ENGLISH	METRIC
1 in.	2.54 cm.
1 lb.	453.6 gm.
1 sec.	1 sec.
1 sq. in.	6.452 sq. cm.
1 cu. in.	16.39 c.c.
1 liquid qt.	.945 liter (liquid unit)

Using this table we can change from any reading in one system to the corresponding readings in the other system.

272. Force. — Besides *space, mass,* and *time* there are many other physical quantities which have to be measured. One of these is *force.*

Force is a push, or a pull, on an object, that tends to make the object move. The force may, or may not, make the object move, but it always *tends* to do so. For example, you can pull on a chair and make it slide on the floor. Again, you can pull or push on the corner of a house, and it will not move, but there is a tendency to move, and if the push or pull were large enough, it would move. These are examples of force.

273. Units of Force. — Force is measured in both the English and metric systems.

The unit most used in the English system is the *pound.* You will notice that this is the same name as that given to the unit of mass, but the idea is different.

A *pound mass* is a certain amount of matter. *A pound force is the pull of the earth on a pound mass at sea level.*

The unit most used in the metric system is the *gram.* Again, this is the same name as that given to the unit of mass, and, as in the English system, *it represents the pull of the earth on a gram mass at sea level.*

274. Work. — When a *force* produces *motion,* it is said to do *work.* Work is a definite physical quantity and can be measured. When you pull on a chair, and it slides on the floor, you do work; but if you do not pull hard enough to make it slide or move, there is no work done.

Work is the result of a force acting against a resistance and moving it. The amount of work is measured by the force multiplied by the distance the force moves.

$$\textit{Work} = \textit{Force} \times \textit{Distance}.$$

It will be seen that if the object is not moved, no work will be done; or, if the body be moving without any force applied, no work is done.

275. Units of Work. — The unit of work in the English system is the *foot-pound,* and in the metric system it is the *gram-centimeter.*

A foot-pound is the work done when a pound force acts through a distance of one foot.

If you were to pull a chair on the floor a distance of 3 ft. and it took a force of 5 lb., the work done would be

$$3 \times 5 = 15 \, ft. \, lb.$$

To find the work done, multiply the force by the distance it moves.

CHAPTER XXII

MACHINES

276. Machines. — *A machine is a mechanical apparatus which either transforms or transfers energy.* There are six simple machines. They are *lever, wheel and axle, inclined plane, pulley, screw,* and *wedge.*

All other machines are composed of a combination of one or more of these six. For example, a sewing machine has a combination of the lever, pulley, and screw. Even the most complicated machine, such as the modern printing-press, is made of groups of the six simple machines.

277. The Lever. — The lever consists of a rigid bar (B) Figure 244, a weight (W), a force (F), and a pivot (P). W represents the *force overcome,* which is often the weight of an object being lifted; F represents the *force applied;* while P is the *point* about which the bar turns.

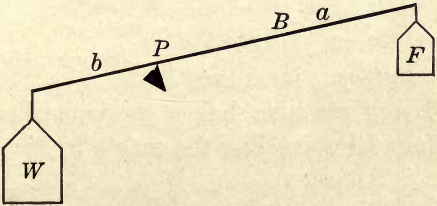

FIGURE 244. — THE LEVER.

The distance (a) from the force to the pivot is called the *force-arm.* The distance (b) from the weight to the pivot is called the *weight-arm.* The product of the force and the force-arm is the *force moment* ($F a$), and the product of the weight and weight-arm is the *weight moment* ($W b$).

The law of the lever is that the *force moment equals the weight moment*, or $F a = W b$.

278. Classes of Levers. — Levers are divided into three classes, according to the relative positions of the force, the weight, and the pivot.

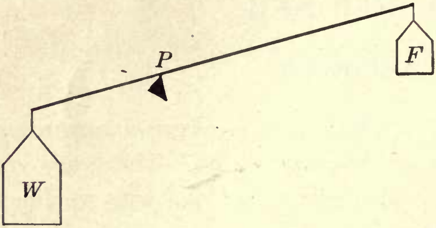

FIGURE 245. — FIRST CLASS LEVER.

The *first class* has the weight and the force on the ends and the pivot in the middle. (Figure 245.)

The *second class* has the force and the pivot on the ends and the weight in the middle. (Figure 246.)

The *third class* has the weight and the pivot on the ends and the force in the middle. (Figure 247.)

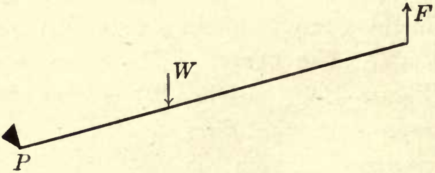

FIGURE 246. — SECOND CLASS LEVER.

279. Mechanical Advantage. — In discussing a machine, the term *mechanical advantage* is used. Every machine has a mechanical advantage, and this is found by dividing the *weight* by the *force*, or by finding an equal ratio. Thus it has a definite meaning, and is defined as the fraction $\frac{W}{F}$.

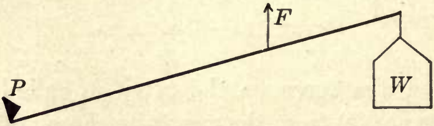

FIGURE 247. — THIRD CLASS LEVER.

In the case of the lever $\frac{a}{b} = \frac{W}{F}$. (Figure 244.) Therefore to find the mechanical advantage of a lever, divide the force-arm by the weight-arm, or

$$Mechanical\ advantage = \frac{Force\text{-}arm}{Weight\text{-}arm}.$$

280. Efficiency. — Another term used in discussing a machine is *efficiency.* This term also has a definite meaning, and is defined as the fraction $\frac{work\text{-}out}{work\text{-}in}$.

No machine will do work of its own accord. Work must first be put into it, and then it will do work, giving a certain amount out. The *work-in* is the work put into the machine. The *work-out* is the work that the machine gives out when operated.

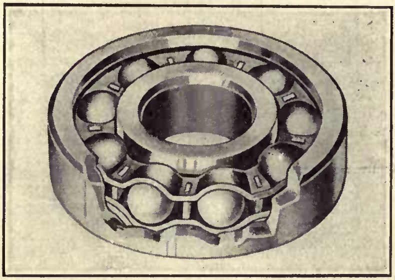

FIGURE 248. — BALL BEARINGS REDUCE FRICTION AND INCREASE THE EFFICIENCY.

A machine never gives out as much work as is put into it, because some of the work is always lost *in* the machine, overcoming friction. Therefore the efficiency of a machine is always less than 100 per cent.

In the case of a lever there is usually very little friction and so the efficiency is usually from 95 per cent to 99.9 per cent.

281. Applications of the Lever. — There are many applications of the lever, but one that needs especial mention is the balance used for weighing objects. (Figure 249.)

The balance consists of a beam (B) supported on a knife-edge (K). At each end of the beam is hung a scale pan (S). These are also supported on knife-edges. A pointer (P)

is attached to the beam to show when a balance of the weights is obtained.

To make a weighing, the object to be weighed is placed in the left-hand pan and is the *W* of the lever. Standard weights are placed in the right-hand pan, so that a balance is obtained.

The best method to get a balance is to start with the largest weight. If it is too small, add the next one, and so on. If it is too large, take it off and use the next smallest. Repeat this operation until a balance is obtained, that is, until the pointer will swing the same distance on one side as on the other.

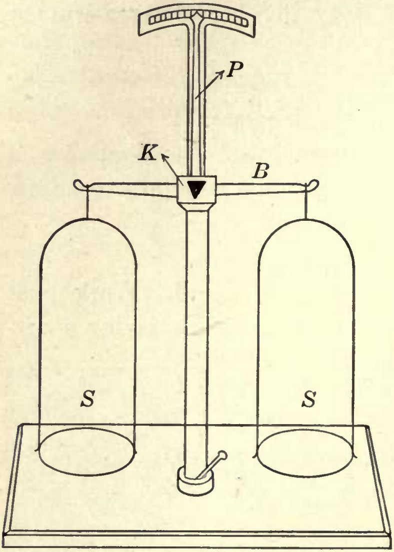

FIGURE 249.—THE WEIGHING BALANCE IS A LEVER.

The balance is a lever of the *first class*. Other examples are shown in Figures 250, 251, 252.

Figures 253, 254, 255 show applications of the *second class* lever.

Figures 256, 257, 258 show applications of the *third class* lever.

Make a simple drawing and classify the levers in the following examples.

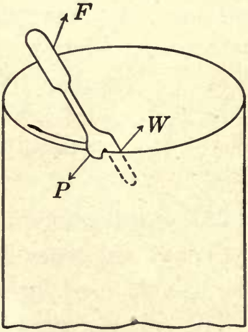

FIGURE 250.—THE CAN OPENER USED AS A FIRST CLASS LEVER.

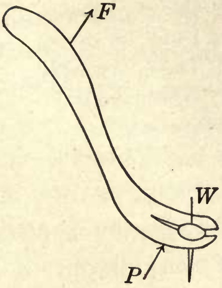

FIGURE 251.—THE TACK PULLER USED AS A FIRST CLASS LEVER.

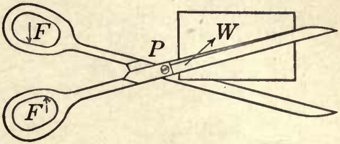

FIGURE 252.—SCISSORS ILLUSTRATE A FIRST CLASS LEVER.

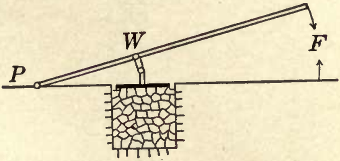

FIGURE 254.—A POTATO RICER USED AS A SECOND CLASS LEVER.

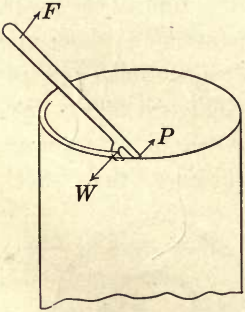

FIGURE 253.—A CAN OPENER USED AS A SECOND CLASS LEVER.

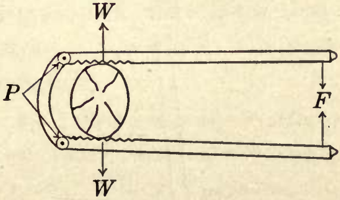

FIGURE 255.—A NUT CRACKER IS A SECOND CLASS LEVER.

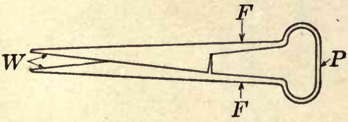

FIGURE 256.—GRASS CUTTERS OR SHEEP SHEARS ILLUSTRATE THIRD CLASS LEVER.

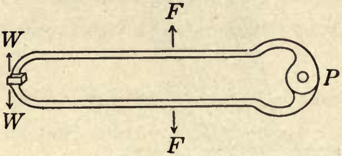

FIGURE 257.—THE SUGAR TONGS IS A THIRD CLASS LEVER.

1. Wire pliers
2. Pitcher pump
3. Lemon squeezer
4. Spoon
5. Knife
6. Fork
7. Claw hammer pulling a nail
8. Oar of rowboat
9. Paddle of canoe
10. The human arm
11. Wheelbarrow
12. See-saw
13. Spring-board
14. Shovel

Name five other applications of the lever, and classify them.

282. Wheel and Axle. — The wheel and axle is another simple machine very similar in action to the lever.

It consists of a wheel and an axle rigidly fastened together. (Figure 259.) The force (*F*) acts on a rope wound around the wheel,

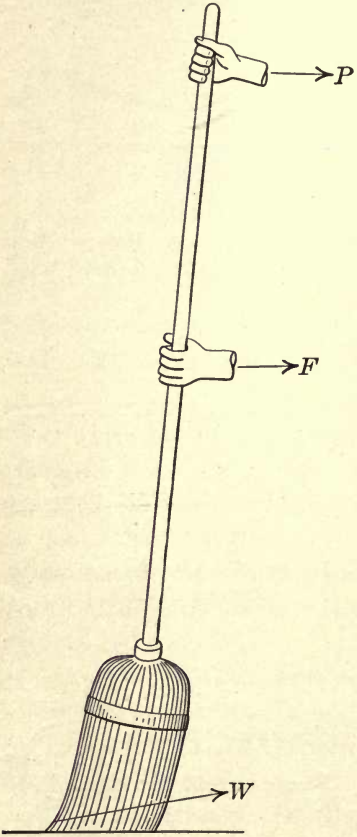

Figure 258. — A Broom Used as a Third Class Lever.

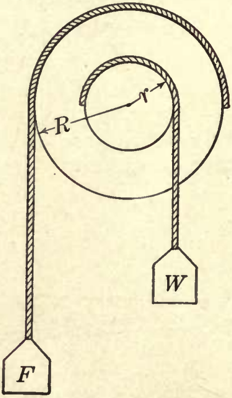

Figure 259. — The Wheel and Axle.

and the weight (W) is hung on a rope wound in the opposite direction on the axle.

When the force moves down, the weight moves up. The action is the same as in the lever. The radius (R) of the wheel acts as the force-arm, and the radius (r) of the axle acts as the weight-arm.

The mechanical advantage of the wheel and axle is $\frac{W}{F}$ or, as in the lever, $\frac{R}{r}$.

The efficiency of this machine is less than that of the lever, ranging from 60 per cent to 99 per cent. The efficiency depends upon the bearings of the machine and upon the flexibility of the cord.

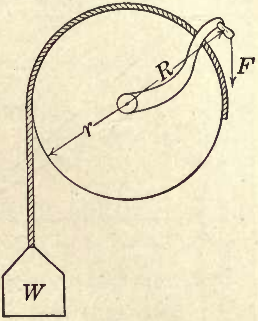

FIGURE 260.—ANOTHER FORM OF THE WHEEL AND AXLE.

Sometimes a crank is used instead of the wheel. (Figure 260.) This does not change the action.

283. Applications of Wheel and Axle. — The windlass used in removing dirt from wells or manholes in the street is an application of the wheel and axle. (Figure 261.)

Another application of the wheel and axle is the device used for raising awnings. (Figure 262.)

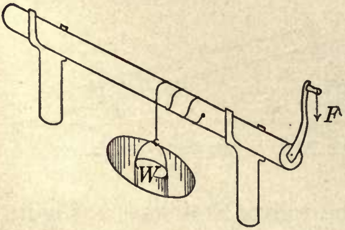

FIGURE 261.—THE WINDLASS IS A WHEEL AND AXLE.

Name and draw two other applications of the wheel and axle.

284. Inclined Plane.—The inclined plane consists of a plane set at an angle to the horizon. (Figure 263.) The weight (W) always acts *downward*, and the force (F) acts *along* the plane. The vertical distance (h) is called the *height of the plane*, while the distance along the plane (L) is called the *length of the plane*.

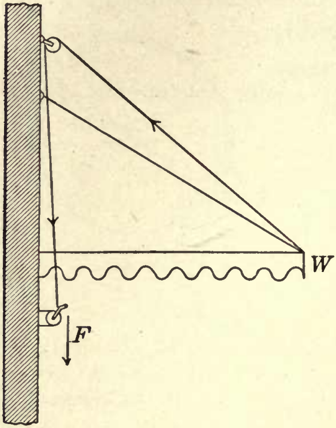

FIGURE 262. — A WHEEL AND AXLE IS OFTEN USED TO LIFT AWNINGS.

The force (F) must move the length of the plane (L) in order to raise the weight (W) the height (h).

The mechanical advantage of the inclined plane is $\frac{W}{F}$ or $\frac{L}{h}$. It will be seen from this that the more nearly the plane comes to the horizontal, the greater will be the mechanical advantage. Then, in order to lift a large weight, use a *long* plane.

285. Applications of Inclined Plane. — There are many applications of the inclined plane. Figure 264 shows an inclined plane used for loading a piano into a truck. A heavy plank is used for the plane and the height of the truck is the height of the plane. By this means one or two men can push the piano into the truck.

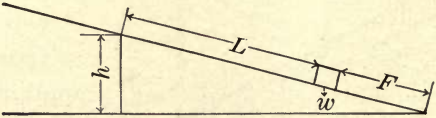

FIGURE 263. — THE INCLINED PLANE.

Another application of the inclined plane is the rolling stairway. (Figure 265.) This is often used in large department stores instead of elevators. A person wishing to go from one floor to another steps on the moving stairway and is carried up, or down, according to the direction in which the stairway moves. Usually there are two of these side by side, one going up, and the other down.

Graded roads are excellent examples of inclined planes.

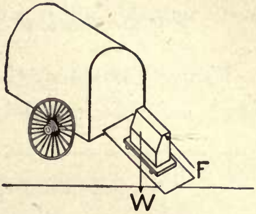

Figure 264. — An Inclined Plane Used to Load a Piano into a Truck.

286. Pulley. — There are two types of pulleys. (Figure 266 and Figure 267.)

Figure 266 shows two pulleys belted together. The one which supplies the power is called the *driver,* and the other the *driven.* The larger the driven pulley is, the greater the mechanical advantage.

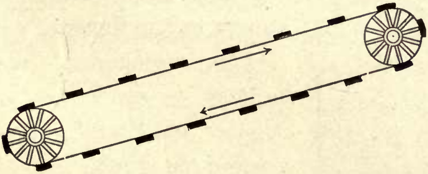

Figure 265. — A Moving Stairway Is an Inclined Plane.

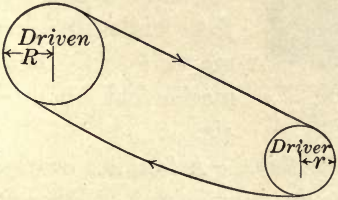

Figure 266. — Two Pulleys Belted Together.

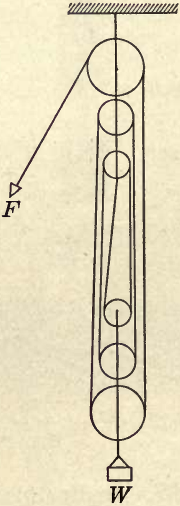

Figure 267. — Another Type of Pulley.

$$\text{The mechanical advantage} = \frac{\text{radius of driven}}{\text{radius of driver}} = \frac{R}{r}.$$

Figure 267 shows the other type of pulley, often called a *block*. A block consists of one or more pulleys or *sheaves* fastened side by side, or one above the other, so that they are free to turn.

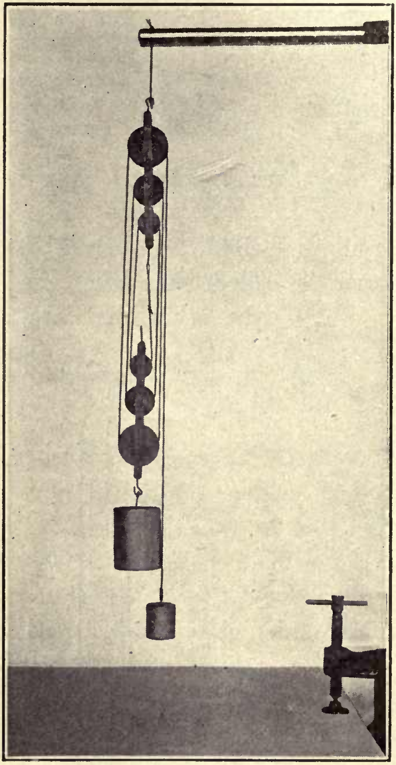

FIGURE 268. — A LABORATORY SET OF PULLEYS.

Two blocks are used to lift a weight. One block is made fast, and the weight is attached to the other one. A rope or chain is threaded through the blocks, as shown in the figure.

The mechanical advantage is equal to the number of strands supporting the weight.

From the figure it will be seen that if the weight be lifted 1 *foot*, there are *six* strands to be shortened 1 *foot*. This allows the force (F) to move 6 *feet* while the weight moves 1 *foot*. Thus the mechanical advantage is *six*.

287. Applications of the Pulley. — A familiar example of the first type of pulley is the sewing machine. (Figure 269.) Here the large wheel is the *driver*, and the small wheel is the *driven.* This arrangement makes it harder to turn, but a greater speed can be obtained.

The revolutions per minute (R. P. M.) of two pulleys belted together are inversely as their diameters. This means that the large pulley runs *slowly* while the small one runs *fast.*

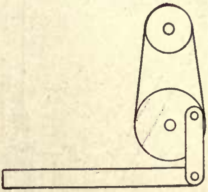

FIGURE 269.—THE PULLEY AS USED IN THE SEWING MACHINE.

Problem: If a driver is 2 ft. in diameter, and makes 500 R. P. M., what is the speed of the driven, which is $\frac{1}{2}$ ft. in diameter?

The second type of pulley is often used in lifting safes or other heavy objects. (Figure 270.) A gin pole is placed in the window above, and the upper block is fastened to this. By pulling on the free end of the rope the safe is raised to the open window. From here it is swung inside.

Elevators are usually lifted up and let down by means of this type of pulley.

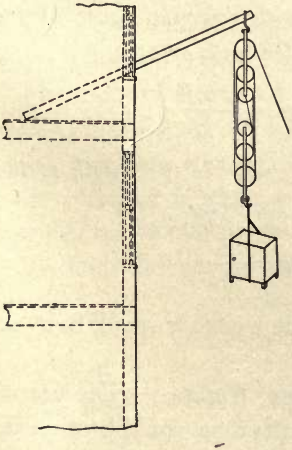

FIGURE 270.—A SET OF PULLEYS USED TO LIFT HEAVY OBJECTS TO THE UPPER STORIES OF HIGH BUILDINGS.

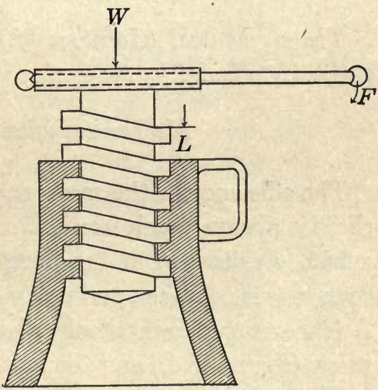

FIGURE 271.—A JACK SCREW.

288. Screw and Wedge. — The screw and the wedge are both very much the same as the inclined plane. As is shown by Figure 271, the screw is merely a spiral inclined plane which is made to move under the weight, thus forcing the weight to move.

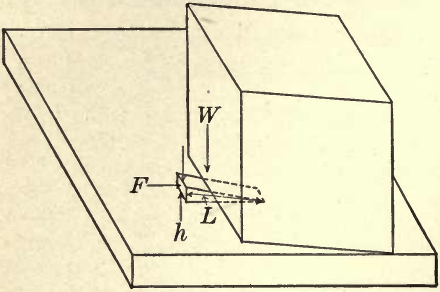

FIGURE 272. — A WEDGE.

Likewise Figure 272 shows that the wedge is a double inclined plane, made to move under the weight, causing the latter to move.

The *pitch* of a screw is the number of threads per inch, and the distance from one thread to the next is called the *lead* (L). *The mechanical advantage is the circumference of the circle that the force moves divided by the lead, or*

$$\textit{Mechanical advantage} = \frac{2\pi R}{L}.$$

The mechanical advantage of the wedge is the length of the wedge (L) *divided by the thickness of the wedge* (h), *or*

$$\textit{Mechanical advantage} = \frac{L}{h}.$$

The efficiency of the screw and the wedge is small, because there is always much friction.

289. Application of the Screw and Wedge. — The use of the screw is common, and many illustrations could be named. A few are the piano stool (Figure 273), the ordinary wood screw (Figure 274), and the bolt and nut (Figure 275).

The wedge is not in such common use, but many examples can be found. Figure 276 shows a hatchet used as a wedge to split kindling.

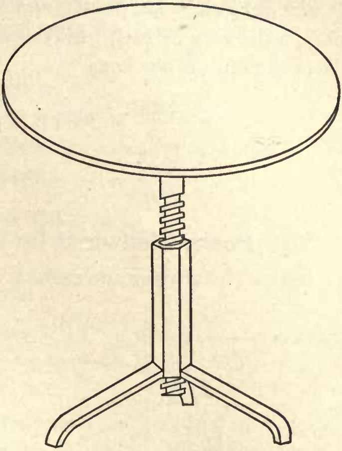

Figure 273. — The Piano Stool Is an Application of the Screw.

290. Power. — *Power is the time rate of doing work.* It is very often confused with the term *work;* but it is different, for it involves the idea of *time,* while work does not.

A boy could carry a thousand bricks up a ladder 10 ft. high as well as a man, but it would take him longer.

The amount of work done by the boy and man would be the same, but the rate at which the man would do the work would be greater; so we say he has the more *power.*

The units of power are the *foot-pound per second,* and the *gram-centimeter per second.* These units are so small that larger units are commonly used. The *horsepower* is the one most common in this country. *A horsepower is the power that will do* 33000 *foot-pounds of work per minute.*

To find the horsepower delivered in any case, find the work in foot-pounds done per minute, and divide by 33000; thus:

Figure 274. — The Wood Screw.

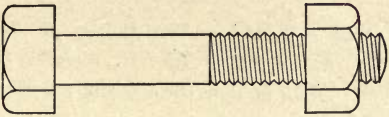

Figure 275. — The Bolt and Nut Is an Application of the Screw.

If a girl weighs 120 pounds and climbs the stairs from one floor to the next, a distance of 15 ft., in 30 seconds, she does 120 × 15 = 1800 ft.-lb. in .5 min. (30 sec.) or

$$\frac{1800}{.5} = 3600 \text{ ft.-lb. per min.}$$

$$\frac{3600}{33000} = \frac{6}{55} = 0.109^{+} \text{ horsepower.}$$

291. Power Delivered by Pulleys. — It is often desirable to know the power necessary to run certain appliances in the home, such, for example, as the sewing-machine, the vacuum cleaner, the washing-machine, food chopper, bread mixer, etc. Most of these are either run by pulleys driven by belts or by gears, so the method for finding the horsepower is the same.

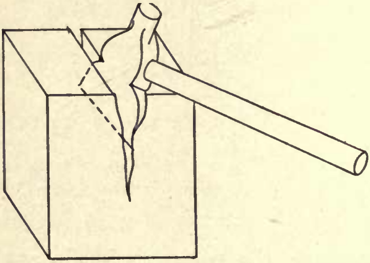

FIGURE 276. — THE HATCHET USED IN SPLITTING KINDLING IS AN APPLICATION OF THE WEDGE.

Let us compute the horsepower for a sewing machine as an example.

Suppose the small 3-in. wheel of the sewing machine must make 500 R. P. M., and that the belt has an effective pull of 2 lb. What is the horsepower necessary to run it?

Method :

$$3 \text{ inches} = \frac{3}{12} = .25 \text{ ft.}$$

$$.25 \times 3.1416 = .7854 \text{ ft., cir. of wheel}$$

$$.7854 \times 500 = 392.7 \text{ ft., distance the belt moves in 1 min.}$$

$$392.7 \times 2 = 785.4 \text{ ft.-lb. per min.}$$

$$\frac{785.4}{33000} = .0238, \text{ horsepower required.}$$

What horsepower is necessary to run a food chopper that requires a force of 10 lb. on the end of a 1-ft. crank making 60 R. P. M.?

Method:

$$\begin{aligned}
2 \text{ ft.} &= \text{diameter of circle} \\
2 \times 3.1416 &= 6.2832 \text{ ft., cir. of circle} \\
6.2832 \times 60 &= 376.992 \text{ ft., distance force moves in 1 min.} \\
376.992 \times 10 &= 3769.92 \text{ ft.-lb. per min.} \\
\frac{3769.92}{33000} &= .114\text{, horsepower required.}
\end{aligned}$$

Problems

1. The pulley on a washing-machine is 10″ in diameter and makes 100 R. P. M. The belt has an effective pull of 25 lb. What horsepower is required?

2. The pulley on a kitchen power-table is 6″ in diameter and makes 600 R. P. M.; the effective pull on the belt is 10 lb. What horsepower is required?

3. If a motor of 80 per cent efficiency runs the pulley in Prob. 1, how many watts does it require? (746 watts = 1 horsepower.)

4. If a motor of 85 per cent efficiency runs the pulley in Prob. 2, how many watts does it require?

5. When you turn an ice-cream freezer handle 1 ft. long, 50 R. P. M., and it requires a force of 8 lb., what horsepower are you producing?

CHAPTER XXIII

DYNAMICS

292. Motion. — *Motion is a change of position with reference to some other object.*

If you were to look at a book lying near the center of a table and were then to close your eyes, and if, while they were closed, some one were to change the book to the edge of the table, could you tell that it had been moved, when you opened your eyes? You say "Yes"; for it has changed its position with reference to the table.

Now, if you were to try the experiment again, and the person changed the table and let the book remain in the center of the table, could you tell whether the book had been moved? Some would say "Yes," and some "No." Both are right and both are wrong, depending on what is taken as a point of reference. Explain.

293. Newton's Three Laws of Motion. — It always takes force to produce, or to change, motion. A chair cannot be moved unless some force is applied. Also, anything in motion requires a force to stop it or make it change its direction.

Newton learned this fact and put it into three laws:

1. *Every body continues in a state of rest, or of uniform motion in a straight line, unless acted upon by some external force.*

2. *Every motion is proportional to the acting force, and takes place in the direction in which the force acts.*

3. *To every force there is an equal force in the opposite direction.*

294. Meaning and Application of Newton's Laws. — *The first law* means that if a body is at rest, it has a tendency to remain at rest. This is shown when you undertake to move a table or some other heavy object, even though it be on casters. On the other hand, a body in motion tends to keep on going in a straight line. This is illustrated by the skidding of an automobile, either around corners or when the brakes are set quickly.

The tendency which a body has to remain at rest, when at rest, or to continue in motion, when in motion, is called *inertia.* It is the inertia of your body which throws you over in a street car when it turns a corner, or which jerks you backward or forward when the car starts or stops suddenly.

The second law means that the resulting motion is doubled if the force is doubled, or multiplied by 3 if the force is multiplied by 3, etc. It also means that the object tends to move in the direction in which the force acts.

To illustrate: If you throw a ball with a certain force, it will have a certain quantity of motion; but, if it is thrown with *twice* the force, it will go *twice* as fast; also it will go in the direction in which it is thrown, if no other force acts upon it.

The third law means that there is always a force, called the *reaction,* which acts in the opposite direction to any given force.

To illustrate this, consider your own weight. This force is downward, but the floor pushes upward with the same force; otherwise you would go through the floor. You cannot take hold of your shoe-tops and lift yourself, for every pound that you lift is counteracted by a pound in excess of your weight which is pushed downward by your feet.

295. The Parallelogram of Forces. — When two forces act upon a body, the body cannot move in both directions, but moves in the direction of the resultant of those two forces.

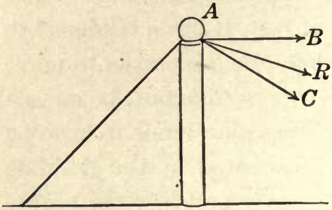

FIGURE 277.— A CLOTHES-LINE POST WITH BALANCED FORCES.

For example, a clothes-line post, as in Figure 277, cannot move in both the directions AB and AC, but tends to move along the resultant AR, which is somewhere between AB and AC.

To find the resultant of two forces such as those mentioned above we use what is called the *parallelogram of forces*.

First, lay off to scale lines representing the forces in both *amount* and *direction*. (Figure 279.)

For example, if the force AB were 50 pounds, and the force AC were 30 pounds, let 5 inches represent the 50 pounds and 3 inches represent the 30 pounds. Upon these two sides construct a parallelogram. The diagonal, which is 5.83 inches, represents the resultant of 5.83 × 10 = 58.3 pounds.

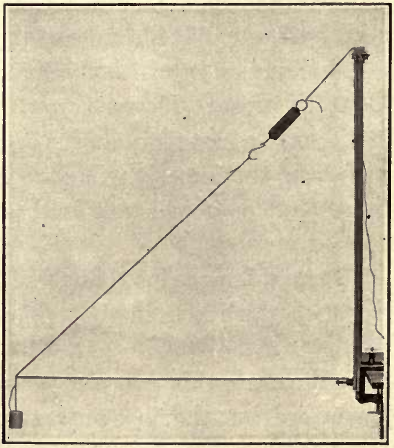

FIGURE 278. — A LABORATORY EXPERIMENT SHOWING BALANCED FORCES.

In this way the resultant of any two forces may be found. If the original forces are laid off to a certain scale, then the *length* of every line in the figure represents the *amount* of force in that line.

296. Applications of Parallelogram of Forces. — The parallelogram of forces can be used to determine the tension in the wires in picture-hanging.

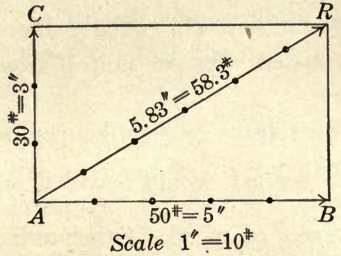

FIGURE 279. — THE PARALLELOGRAM OF FORCES.

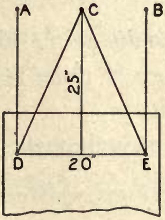

FIGURE 280. — THE PARALLELOGRAM OF FORCES APPLIED TO PICTURE HANGING.

Figure 280 shows a picture hanging from a hook in one of the usual ways. The distance between the supporting screws in the picture is 20 in. The distance from the hook to the line of screws is 25 in. Find the tension in each wire, if the picture weighs 10 pounds.

Method:

If the picture were supported from two hooks (A and B), the wires would each be 25 in. long and would support $\frac{10}{2} = 5$ pounds.

Since each line in the figure represents the amount of force in that line, then

$$25 \text{ in.} = 5 \text{ lb.}$$

$$1 \text{ in.} = \tfrac{1}{25} \text{ of } 5 = \tfrac{1}{5} \text{ lb.}$$

$$\text{The actual wire } CD = \sqrt{(AC)^2 + (AD)^2} =$$

$$\sqrt{10^2 + 25^2} = \sqrt{100 + 625} = \sqrt{725} = 26.9^+$$

$$\therefore \text{ the tension in } CD = 26.9 \times \tfrac{1}{5} = 5.38 \text{ lb.}$$

Problems

1. Find the tension in the wire of a picture hung from a hook which is 12 in. above the line of the screws in the picture, if the two screws are 18 in. apart and the picture weighs 8 lb.

2. What is the tension in a guy-wire for a clothes-line post, if the post is 6 ft. high and the guy-wire is set 4 ft. from the base of the post, the clothes-line having a tension of 75 lb.?

297. Velocity and Acceleration. — Any body in motion has a definite *speed* or *velocity* — two terms meaning the same thing.

Velocity is the time rate of motion. This means that the number of units of distance passed over per unit of time is velocity.

To say that the velocity of a train is 30 miles per hour (sometimes written $30\ \frac{mi.}{hr.}$) means it would travel 30 miles in one hour, if it ran at that rate of speed. Other units of velocity are

$$\frac{ft.}{sec.},\ \frac{cm.}{sec.},\ \frac{km.}{hr.},\ \text{etc.}$$

If the speed of an object is the same continuously, it is said to have *uniform velocity.* But if the velocity changes it is said to be *accelerated.*

Acceleration is the change in velocity per unit time. For example, if a body starts from rest and is going at the rate of $5\ \frac{ft.}{sec.}$ at the end of the first second; $10\ \frac{ft.}{sec.}$ at the end of the second second; $15\ \frac{ft.}{sec.}$ at the end of the third second, etc., the motion is said to have an acceleration of 5 ft. per second, per second, meaning that it has gained $5\ \frac{ft.}{sec.}$ of velocity every second.

Acceleration is either *positive* or *negative,* according as the change in velocity is an increase or a decrease.

The pull of gravity gives all bodies an acceleration downward of 32.2 ft. per second, per second, or 980 cm. per second, per second. This is called the acceleration due to gravity, and is represented by the letter g.

298. Uniformly Accelerated Motion. — When a body is uniformly accelerated, it is very often desirable to find:

(1) The velocity (v) in terms of the acceleration (a) and the time (t) which the body has traveled —

$$v = at;$$

(2) The distance (S) which the body has traveled in terms of the acceleration (a) and the time (t) which the body has traveled —

$$S = \tfrac{1}{2}\, at^2;$$

(3) The distance (d) which the body has traveled in any *particular second* in terms of the acceleration (a) and the second (t) in question —

$$d = \tfrac{1}{2}\, a\,(2\,t - 1);$$

(4) The velocity (v) in terms of the acceleration (a) and the distance passed over (S) —

$$v^2 = 2\,aS.$$

The following problems illustrate the use of these formulæ:

Problem (1): What is the velocity of an automobile at the end of 5 seconds, if it has an acceleration of 2 ft. per second, per second?

Method:

$$v = at$$

$$\therefore\ v = 2 \cdot 5 = 10\,\frac{ft.}{sec.} \quad \text{(ans.)}$$

Problem (2): How far will a train travel in 10 seconds, if it has an acceleration of $\frac{1}{2}$ ft. per second, per second?

Method:

$$S = \tfrac{1}{2}\, at^2$$

$$\therefore\ S = \tfrac{1}{2} \cdot \tfrac{1}{2}.\quad 10^2 = \tfrac{1}{2} \cdot \tfrac{1}{2} \cdot 100 = 25 \text{ ft.} \quad \text{(ans.)}$$

Problem (3): How far will a train travel during the 8th second after starting, if it has an acceleration of $\frac{1}{2}$ ft. per second, per second?

Method:

$$d = \tfrac{1}{2}a\,(2\,t - 1)$$
$$\therefore d = \tfrac{1}{2}\cdot\tfrac{1}{2}(2\cdot 8 - 1) = \tfrac{1}{2}\cdot\tfrac{1}{2}(16 - 1)$$
$$= \tfrac{1}{2}\cdot\tfrac{1}{2}\cdot 15 = 3\tfrac{3}{4}\,ft. \quad \text{(ans.)}$$

Problem (4): What is the velocity of an automobile after it has gone 25 ft., if it has an acceleration of 2 ft. per second, per second?

Method:

$$v^2 = 2\,aS$$
$$\therefore v^2 = 2\cdot 2\cdot 25 = 100$$
$$v = \sqrt{100} = 10\,\frac{ft.}{sec.} \quad \text{(ans.)}$$

All the examples above were given in the English system. The same formulæ and methods of solution are used in the metric system. Instead of feet use centimeters.

Since the pull of the earth gives all bodies a uniform acceleration, these same formulæ apply to freely falling bodies.

For falling bodies the above formulæ may be written and used in the special forms:

$$v = gt.$$
$$S = \tfrac{1}{2}\,gt^2.$$
$$d = \tfrac{1}{2}\,g(2\,t - 1).$$
$$v^2 = 2\,gS.$$

299. Momentum. — *The quantity of motion which a body possesses is called momentum.* It is measured by multiplying the mass of a body by its velocity. Thus an automobile weighing 2500 lb. and going $20\,\frac{mi.}{hr.}$ has $2500 \times 20 = 50{,}000$ lb.-miles per hour of momentum.

Likewise, a baseball weighing 5 oz. and going 100 ft. per sec. has a momentum of $\frac{5}{16}\cdot 100 = 31\frac{1}{4}$ lb.-ft. per sec.

There is no definite unit for momentum, so terms such as *lb.-mi. per hr., lb.-ft. per sec.,* etc., have to be used. In comparing momenta, care must be taken that they are expressed in the same units.

300. Force to Overcome Inertia. — By Newton's first law of motion every body tends to remain at rest or to continue in a straight line at a uniform speed unless some force acts upon it; hence a force setting a body in motion (or stopping its motion) must overcome this inertia, together with the other forces acting upon the body, such as friction, weight, etc.

The force to overcome inertia is proportional to both the *mass* of the body and the *acceleration* given it. Thus:

$$F = Ma \qquad (1)$$

or

$$F = \frac{Wa}{g}. \qquad (2)$$

If the mass is given in grams and the acceleration in centimeters per second, per second, equation (1) *gives the force in dynes. If the weight is given in pounds or grams and the acceleration in feet per second, per second, or centimeters per second, per second, equation* (2) *gives the force in pounds or grams respectively.*

Thus a girl weighing 110 lb. and standing in an elevator going down with an acceleration of 2 ft. per second, per second, will apparently weigh 103.2 b.

$$F = \frac{Wa}{g}.$$

$$F = \frac{110 \cdot 2}{32.2} = 6.8 \text{ lb.}$$

∴ she weighs 6.8 lb. less than 110 = 103.2 lb., her apparent weight.

If the elevator were going up with an acceleration of 2 ft. per second, per second, she would weigh 6.8 lb. more, or 110 + 6.8 = 116.8 lb., her apparent weight.

The force required to overcome the inertia of *any* body can be found in a similar manner.

301. Force to Overcome Friction. — Excepting the motions of the heavenly bodies, all motions are opposed by a certain amount of friction, so that the force changing the motion of a body must overcome the friction besides overcoming inertia and other forces, such as weight, etc.

In calculating the force necessary to produce motion of a body, each part must be calculated separately and the results added.

302. Centrifugal Force. — Any body moving in the circumference of a circle (Figure 281) tends to fly away from the center. This is due to Newton's first law of motion. Explain.

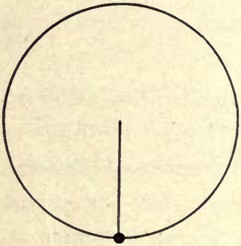

FIGURE 281. — CENTRIFUGAL FORCE.

The force tending to throw the body away from the center is called the *centrifugal force.*

A pail of water may be swung in a vertical plane without spilling the water on account of the centrifugal force. Centrifugal force causes vehicles to skid around corners. The cream separator uses centrifugal force to separate the cream from the milk. This can be done because cream is lighter than plain milk.

303. Energy of Motion. — All bodies in motion have energy due to that motion. An automobile moving 60 mi. per hour will do more damage, if it smashes into a building, than if it were running 10 mi. per hour. A hammer swung with the arm will drive a nail farther than if the hammer were just laid on the nail. These are all illustrations of energy of motion, usually called *Kinetic Energy* (*KE*).

$$KE = \frac{Wv^2}{2\,g}.$$

The above formula will give the kinetic energy in foot-pounds if W is expressed in pounds; v = *feet per second;* and $g = 32.2$.

304. Gravitation. — Every bit of matter in the universe exerts a pull on every other bit of matter. This pull is called *gravitation.*

The earth, being a very large bit of matter, exerts a pull on all objects on or near it. This pull is called the *weight* of the object.

Newton formulated three laws, called Newton's three laws of gravitation. They are:

1. *The weight of an object at any given place is directly proportional to its mass.*

2. *The weight of an object above the surface of the earth is inversely proportional to the square of the distance from the center of the body to the center of the earth.*

3. *The weight of a body below the surface of the earth is directly proportional to the distance between the center of the body and the center of the earth.*

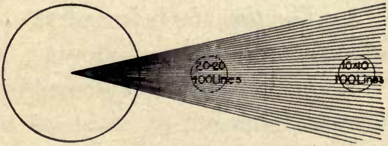

FIGURE 282. — ILLUSTRATING THE SECOND LAW OF GRAVITATION.

The first law needs no explanation. The second law can be made more clear by the use of Figure 282.

It will be seen that the farther the body is away from the earth, the fewer are the lines of gravitation which pass through it. This is why the pull gets less as the distance gets greater.

Figure 283 illustrates the third law. A body inside the earth has part of the earth (*A*) pulling to the right, while the other part (*B*) pulls to the left. Thus we see that the resulting force becomes smaller as the distance between the center of the body and the center of the earth becomes smaller.

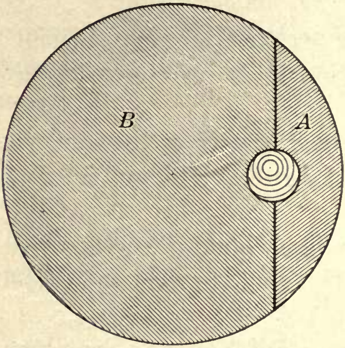

FIGURE 283. — ILLUSTRATING THE THIRD LAW OF GRAVITATION.

305. Pendulum. — A pendulum is a body supported from a pivot and free to swing because of its weight. (Figure 284.) *L* represents the *length* of the pendulum; *a*, the *amplitude* of the swing; *g*, the acceleration due to gravity; *t*, the *time of the pendulum* — the time it takes the pendulum to move from one side of the swing to the other.

There are four laws governing the time of a pendulum:

1. *The time is independent of the mass.*

2. *The time is independent of the amplitude.*

3. *The time is directly proportional to the square root of the length.*

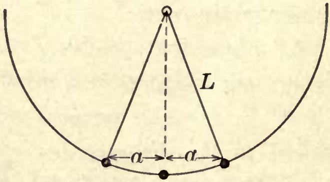

FIGURE 284. — THE PENDULUM.

4. *The time is inversely proportional to the square root of the acceleration due to gravity.*

The pendulum is used to regulate clocks, etc. To make a clock run faster, shorten the pendulum.

CHAPTER XXIV

MECHANICS OF FLUIDS

306. The Three States of Matter. — All matter exists in one or more of three states — *solid, liquid,* or *gas.* Some substances are found in all three states. Water is the most common of these. Other substances existing in the three states are *iron, copper, lead, mercury,* etc.

The *apparent difference* between the three states of matter is as follows:

1. A solid has a definite shape and volume.
2. A liquid has a definite volume, but takes the shape of the containing vessel.
3. A gas has neither a definite shape nor volume, but takes the shape of the containing vessel and fills it completely.

The *theoretical difference* between the three states of matter depends upon the molecular construction of the substance in these different states.

In a solid, the molecules are *close together* and are held firmly together by a force called *cohesion.* This force is sufficient to keep the molecules from changing their relative positions, but it allows them to vibrate.

In a liquid, the molecules are farther apart, and the force of cohesion is not so great. The molecules can slide over one another, but still the force is great enough to keep them from separating.

In a gas, the molecules are far apart, the force of cohesion is too small to count, and the molecules fly about with perfect freedom, bumping against one another and the sides of the containing vessel.

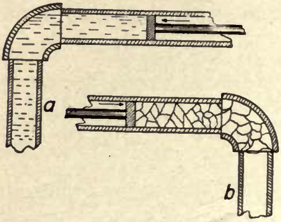

FIGURE 285. — LIQUIDS AND SOLIDS IN PIPES.

307. Gases and Liquids through Pipes. — The fact that gases and liquids have no definite shape makes it possible to deliver them through pipes.

Consider the two pipes (*a*) and (*b*) (Figure 285) filled with water and chunks of coal, respectively, and then a force put on both of them. In the first case, the water molecules would slide over one another at the bend of the pipe, and so would *flow* around the bend; but, in the second case, the chunks of coal would not slip past one another, but would push against the end of the pipe and would *clog the pipe.* A gas would act in the same way as the water.

FIGURE 286. — PRESSURE IS USED IN THE FIRE EXTINGUISHER

Thus we see why it is possible to deliver gas and water through pipes, but why we have to haul our coal, wood, and all other solids.

308. Pressure. — Figure 287 shows a cylinder with water in it, and a piston (K) being forced against the water with a force of 100 lb.

It will be seen that the water will push on the end of the cylinder with a force of 100 lb. If the end of the cylinder has an area of 25 sq. in., this 100 lb. will be distributed over the total 25 sq. in. Thus each square inch will receive $\frac{100}{25} = 4$ lb. (*P*, Figure 287.)

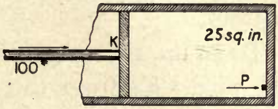

FIGURE 287. — MEANING OF THE TERM "PRESSURE."

The force on the one square inch is called the *pressure.*

Pressure is the force per unit area. It is found by dividing the *force* by the *area* of the surface.

$$P = \frac{F}{A}.$$

Force applies to the *total area,* while *pressure* applies only to *unit area.*

309. Pascal's Law. — In Figure 287 the water would press not only on the *end* of the cylinder, but also on the *sides* ; that is, every square inch of surface would also have a force of 4 lb.; or, as we say, the pressure would be 4 *lb. per square inch.*

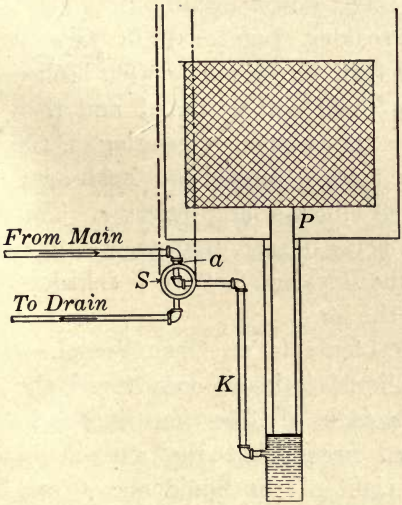

FIGURE 288. — THE HYDRAULIC ELEVATOR.

Pascal stated these facts in the form of a law: *The pressure on a confined liquid is transmitted undiminished in all directions, and acts at right angles to all surfaces.*

310. The Hydraulic Elevator. — The hydraulic elevator (Figure 288) uses the principle expressed by Pascal's Law. A large piston (P) on the bottom of the elevator fits into a cylinder in the ground. A pipe (K) runs down the side of the cylinder and enters it at the bottom.

To go up, the stopcock (S) is turned so that water enters the pipe (K) from the water-main (a). The water flows down the pipe (K) and into the cylinder, pushing up on the piston (P). Since the pressure in the water-main is about 60 lb. per square inch, there is also a pressure of 60 lb. per square inch exerted on the bottom of the piston.

If this piston contains 100 sq. in., the elevator will be pushed up with a force of $60 \times 100 = 6000$ lb.

To come down, the stopcock is turned so that no more water can get into the pipe, but the pipe is opened to the outlet or sewer. The weight of the elevator pushes the water out, and the elevator comes down slowly.

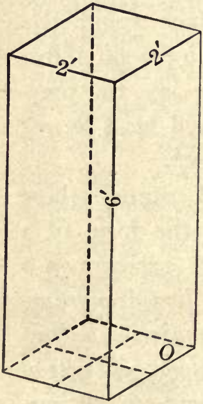

Figure 289. — Pressure in an Open Vessel.

311. Breaking Jugs or Fruit Jars. — Jugs and fruit jars are very often broken by filling them with a liquid and then forcing in the stopper or pressing on the lid. The force is applied to a small area, and this produces a large *pressure*. This pressure being transmitted to the total area of the sides and bottom is sufficient to break the jar.

312. A Liquid in an Open Vessel. — When a liquid is in an open vessel, the pressure acts in all directions, just as in the closed vessel, but the amount of pressure depends on the weight of the liquid above, and not on *an outside force.*

Figure 289 shows water in a rectangular tank 2 ft. square and 6 ft. deep. It is seen that the total weight of the water rests on the bottom. Since water weighs $62\frac{1}{2}$ lb. per cubic foot, the force on the bottom is

$$2 \times 2 \times 6 = 24 \text{ cu. ft.}$$
$$24 \times 62\tfrac{1}{2} = 1500 \text{ lb.}$$

Since the 1500 lb. is on 4 sq. ft.,

$$\text{Pressure} = \frac{1500}{4} = 375 \text{ lb. per square foot,}$$

$$\text{or Pressure} = \frac{375}{144} = 2.6 \text{ lb. per square inch.}$$

It has been proven that the pressure on the bottom of a vessel has nothing to do with the shape of the vessel, but depends solely upon the depth of the liquid and the area of the base.

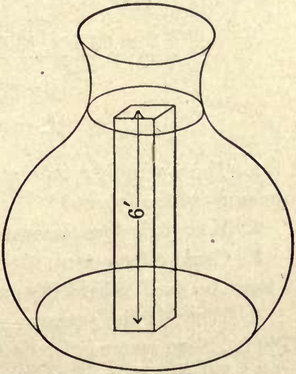

FIGURE 290. — PRESSURE IN AN IRREGULAR SHAPED OPEN VESSEL.

Problem: Find the pressure on the bottom of the irregular vessel filled with water. (Figure 290.)

Assume a column of water 6 ft. high standing on a base one foot square.

Then its

$$\text{weight} = 1 \times 1 \times 6 \times 62\tfrac{1}{2} = 375 \text{ lb.}$$

Thus the pressure is 375 lb. per square foot, regardless of the shape of the vessel.

$$\frac{375}{144} = 2.6 \text{ lb. per square inch.}$$

Rule: *To find the pressure in pounds per square foot of a liquid in an open vessel, multiply the height* (h) *in feet, by the weight of the liquid per cubic foot* (D).

$$P = h \cdot D.$$

If the pressure is wanted in pounds per square inch, divide by 144.

$$P = \frac{h \cdot D}{144}.$$

Problem: What is the pressure in pounds per square inch 20 ft. below the surface of water?

$$P = \frac{h \cdot D}{144}$$

$$P = \frac{20 \times 62.5}{144} = 8.68 \text{ pounds per square inch.}$$

Problem: What is the pressure 3 ft. under mercury, if it is 13.6 times as heavy as water?

$$P = \frac{h \cdot D}{144}.$$

$$P = \frac{3 \times 62.5 \times 13.6}{144} = 17.7 \text{ pounds per square inch.}$$

Problems

1. The water in a tank stands 18 ft. above a faucet. What is the pressure at the faucet?

2. How high does the water rise in the spout of a teakettle?

3. Could a large tank of water, on a level with the second story, and a hose, be used to fight fire on the third story? Why?

4. What is the pressure on a deep-sea diver when he goes down 180 ft., if sea water is 1.1 times as heavy as fresh water?

5. What is the pressure at a faucet on the third floor, if the pressure in the water-main in the basement 45 ft. below is 60 lb. per square inch?

313. Air-Pressure. — Air, like water, has weight, but not so great as water. The atmosphere is estimated to reach from 300 to 400 miles above the surface of the earth; and all this great weight of air above is resting on the lower layers, producing a *pressure* just as the weight of the water above produces a pressure on the water beneath.

At sea-level the air-pressure is *normally* 14.7 lb. per square inch. Places above sea-level have less pressure, because there are fewer layers of air resting on them. The upper layers are not so heavy, since they are less compressed, consequently the pressure falls rapidly as you rise above sea-level.

The air-pressure is measured by an instrument called the *barometer*.

314. The Simple Barometer. — A simple barometer may be constructed in this way: Take a glass tube about 32 in. long, closed at one end, and fill it with mercury. Then invert it in a cup of mercury, being careful not to let in any air. (Figure 291.)

The mercury will fall away from the top of the tube, and stand at 30 in., more or less, according to the air-pressure. The space above the mercury in the tube is almost a vacuum, since there is nothing in it except a little mercury vapor.

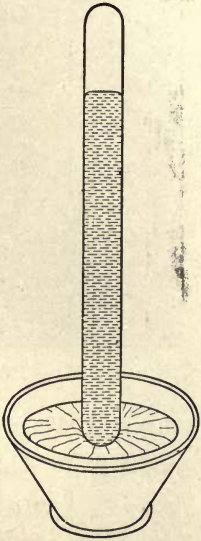

FIGURE 291. — THE SIMPLE BAROMETER.

The pressure of the mercury in the tube is exactly balanced by the pressure of the air on the surface of the mercury in the cup. This pressure can be expressed in *inches of mercury, centimeters of mercury, pounds per square inch,* or *grams per square centimeter.*

If the pressure is wanted in *inches of mercury,* or *centimeters of mercury,* it is read directly from the column of mercury; but if it is wanted in *pounds per square inch,* or *grams per square centimeter,* it has to be calculated as one calculates the pressure in a liquid.

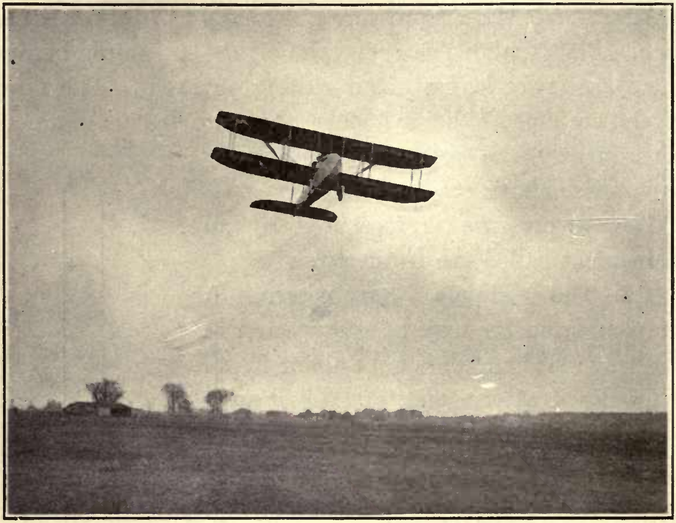

FIGURE 292. — THE *WEIGHT* OF THE AIR MAKES IT POSSIBLE TO FLY.

Example: What is the pressure in *pounds per square inch*, when the barometer reads 28 in.?

$$P = \frac{h \times D}{144}.$$

$$h = \frac{28}{12} \text{ ft.}$$

$$D = 62.5 \times 13.6 = 850 \text{ lb. per cubic foot.}$$

$$\therefore P = \frac{\frac{28}{12} \times 850}{144} = \frac{28 \times 850}{12 \times 144} = 13.77 \text{ lb. per square inch.}$$

315. The Commercial Barometer. — The commercial barometer, which is used for accurate readings of the air-pressure, is a modified form of the simple barometer.

Figure 293 is a diagram of this instrument. The glass tube is inclosed in a brass tube having part of it cut away so that the glass tube can be seen at the upper end. The mercury cup has a rubber or leather bottom, so that it can be raised or lowered by a set-screw (*a*).

A small movable scale (*V*), called a *vernier*, is operated by a set-screw (*b*), and slides at the side of a scale (*S*) marked off in *inches* and *tenths* of *inches*.

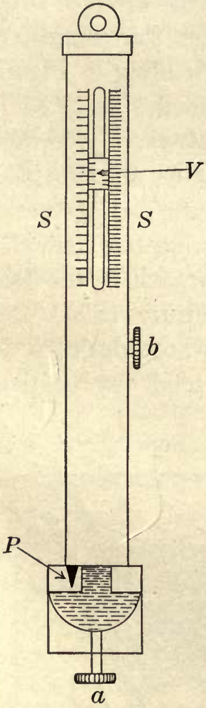

FIGURE 293. — DIAGRAM OF THE COMMERCIAL BAROMETER.

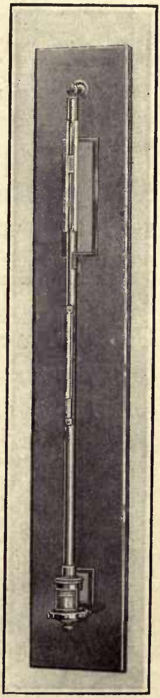

FIGURE 294. — PHOTOGRAPH OF A BAROMETER.

To make a reading: First, adjust the mercury in the cup with the set-screw (*a*) so that the top of the mercury just touches the point of the ivory plug (*P*). This point is the zero of the scale (*S*).

Second, slide the vernier (*V*) by means of screw (*b*) so that the bottom of the vernier is just at the top of the mercury in the tube.

Third, read the scale (*S*) and the vernier (*V*).

Figure 295 shows an enlarged drawing of the scale (*S*) and the vernier (*V*).

First, note where the *zero* of the vernier (*V*) comes on the scale (*S*). In the figure it is *past* 28.3, and *not quite to* 28.4; then the scale reading is the *smaller* of these, or 28.3.

Second, note where a mark on the vernier (*V*) *coincides*

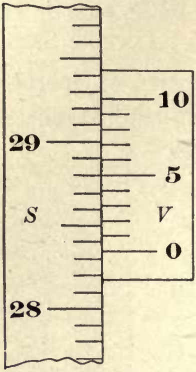

FIGURE 295.—ENLARGED DRAWING OF THE VERNIER OF A BAROMETER.

with a mark on the scale (*S*). In the figure it is 5 on the vernier. (It makes no difference which one on the scale.) This determines the next figure to be annexed to the scale reading, which makes the completed reading. Thus the reading in Figure 295 is 28.3 with 5 annexed, or 28.35″.

316. Weather Maps. — Weather conditions are usually accompanied by certain air-pressure and temperature changes. Knowing this fact, the government has a branch of the Department of Agriculture called the United States Weather Bureau, part of whose duties it is to make weather maps and from them send out weather forecasts.

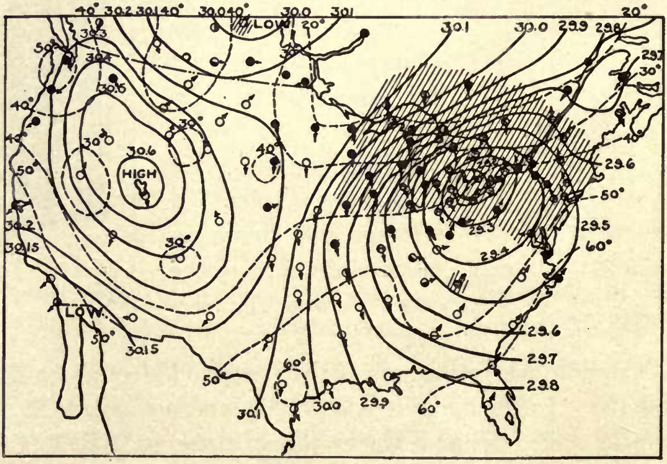

FIGURE 296.—A TYPICAL WEATHER MAP.

The Weather Bureau has stations established all over the United States, and every 24 hours these stations report to the head office at Washington, D. C., on the weather conditions. Some of the things reported are *barometer reading* (reduced to normal conditions), *temperature, clear, cloudy, rain, or snow, direction and velocity of wind.* These reports are then summarized and reported back to all the stations. Each station then draws up a *weather map* and forecasts the local weather for the next 48 hours.

A weather map (Figure 296) is made by drawing heavy lines, called *isobars,* through all stations of equal pressure; dotted lines, called *isotherms,* through all stations of equal temperature; an arrow at each station, indicating the direction of the wind; and small circles marked to show whether it is *clear, partly cloudy, cloudy, rain, or snow,* respectively. The cloudy areas are shaded, the low pressure areas are marked "LOW," and the high pressure areas are marked "HIGH."

For a further study of the weather map read some good physical geography.

317. The Lift-Pump. — Figure 296 is a diagram of the lift-pump, which is an application of air-pressure.

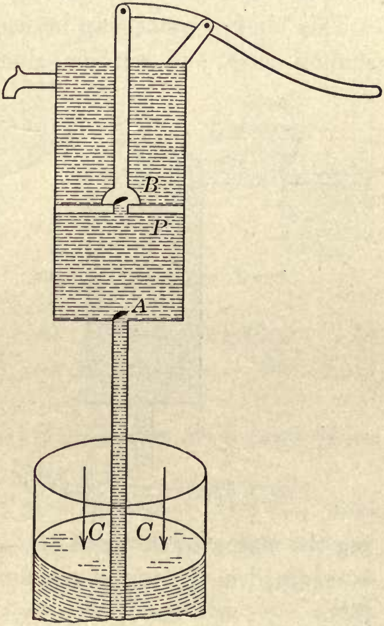

FIGURE 297. — THE LIFT-PUMP.

The piston (*P*) works air-tight in the cylinder of the pump. When the piston is drawn up, the valve (*B*) closes, and a partial vacuum is left behind the piston. The air-pressure, acting on the surface of the water (*C*, *C*) in the well, forces the water up to fill this partial vacuum.

On the down stroke of the piston, valve (*A*) closes and (*B*) opens. After several strokes, the water reaches up into the pump. The operation is continued, and the water flows through the valves, instead of air. When the water gets high enough, it runs out of the spout.

Sometimes the pump will not start, but has to be "primed." This is because the valves or piston will not hold air, so water has to be put in to make them air-tight.

This kind of pump can be used only to pump water from shallow wells and cisterns, since the air-pressure will raise water only 34 ft. under *ideal conditions;* and only about 28 ft., practically.

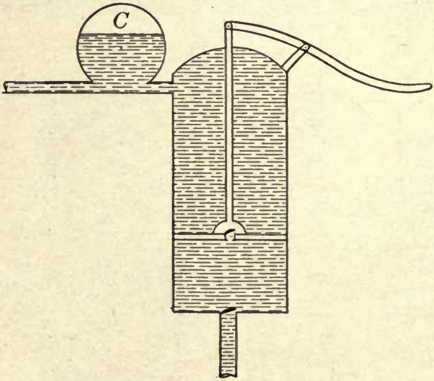

Figure 298. — The Force-pump.

318. The Force-Pump. — The force-pumps used to drive water into mains, pressure tanks, and fire hose are much like the lift-pump, only instead of allowing the water to flow out of the spout of its own accord, it is confined in the top of the pump and *forced* out. (Figure 298.)

An air-chamber (*C*) is attached to the pump, so that the air, when compressed, acts as a spring to keep the pump from bursting and to keep the water flowing between strokes.

319. The Siphon. — Figure 299 represents a siphon, which consists of a tube with its ends in water, at different levels. If the tube is completely filled with liquid, the liquid will run through the tube from the higher level to the lower.

The air-pressure on the surface of the water (*c*) tends to lift the water 34 ft. in the tube. Also the same air-pressure at (*d*) tends to lift the water 34 ft. on the other side of the tube. But the water presses downward on the two sides with a pressure of *a* ft. and *b* ft., respectively. This leaves a pressure of 34 − *a* and 34 − *b*, respectively. Since *b* is greater than *a*, the greater pressure is towards (*b*), and the water runs in that direction. The greater the difference in (*a*) and (*b*), the faster the liquid will flow.

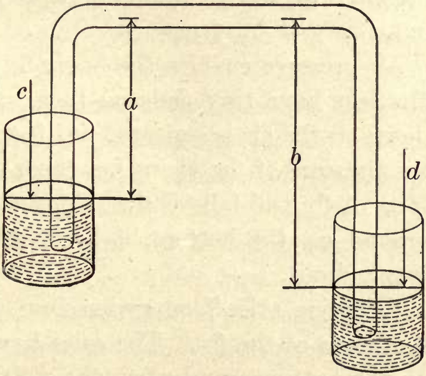

FIGURE 299. — THE SIPHON.

The siphon is used for getting acids out of carboys, cider out of barrels, water out of tanks, etc.

320. Other Applications of Air-Pressure. — Drawing soda water through a straw could not be done if it were not for air-pressure. The air is drawn out of the straw, leaving a partial vacuum, and the air-pressure forces the soda water up to take the place of the air.

Ordinary breathing depends upon air-pressure. The muscles of the chest act and make the cavity in which the lungs are located larger. This reduces the pressure in the lungs, and the air is forced in to equalize the pressure.

Fruit-jar lids are often hard to get off on account of the pressure of the air. When the jar is sealed, the liquid and air in the jar are hot. On cooling, they both contract, thus reducing the pressure inside the jar. The outside air-pressure then holds the lid on very tight. Corks drawn into bottles in the same way are often hard to get out.

Air-pressure enables the house-fly to stick to the ceiling. His feet have tiny pads on them, and when he sets them down all the air is squeezed out from under them, and then the pressure of the air makes them stick to the wall or ceiling. A fly will fall off the side of a bell jar and will crawl around on the bottom, if he is put inside and the air is pumped out.

" Suction soles " on gymnasium shoes are similar to the foot-pads of the fly. The soles have holes, or depressions, on the bottoms, and when the weight of the wearer comes down on them, the air is squeezed out, and then the air-pressure outside tends to make them " stick." " Suction tread " tires work on exactly the same principle.

321. Boyle's Law. — All gases can be compressed by putting pressure on them. That is, more and more gas may be forced into the same space, or a certain amount of gas may be forced into a smaller space. In either case the pressure in the gas is increased.

On the other hand, a gas will expand if allowed space to do it in. In this case the pressure is decreased.

Boyle stated these facts in a law, called *Boyle's Law.*

The volume of a gas at a constant temperature varies inversely as the pressure exerted upon it.

This means that if the pressure is *doubled,* the volume is *halved;* or if the pressure is *halved,* the volume is *doubled,* etc.

The law applies to natural or artificial gas used as a fuel. The higher the pressure, the more gas there is squeezed into a cubic foot; and, since gas is usually sold by the cubic foot, the pressure affects the cost of the gas.

This change in cost due to change in pressure is not as great as some people think. An illustration will show how much the effect is.

Suppose the normal pressure is 6 oz. per square inch. (This is the average pressure maintained for natural gas.) This means 6 oz. per square inch above atmospheric pressure. Since atmospheric pressure is about 14.5 lb., or 232 oz., per square inch, this makes the actual pressure in the gas main $232 + 6 = 238$ oz. per square inch.

Now, if the gas pressure should fall 50 per cent, or to 3 oz. above atmospheric pressure, the actual pressure in the main would be $238 - 3 = 235$ oz. per square inch.

Thus there will be $\frac{235}{238}$ as much gas in a cubic foot as there was at the normal pressure of 6 oz. per square inch.

The inflation of tires with air under pressure is also an application of Boyle's Law.

322. Surface Tension. — All liquids act as if they have a "skin" or "membrane" stretched over their surfaces. A needle may be laid on the surface of water (Figure 300), if care is taken. The surface of the water is curved under the needle just as if there were a cover over the water. This apparent "skin" or membrane is called *surface tension.*

The fact is, there is no membrane on the liquid. The molecules at the surface are exactly the same as inside the liquid. Surface tension is explained as follows:

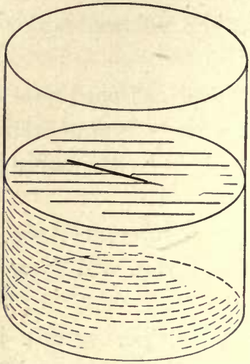

FIGURE 300. — A NEEDLE LYING ON WATER,

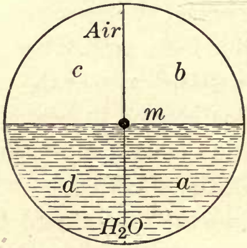

FIGURE 301. — SURFACE TENSION EXPLAINED.

Consider a molecule of water (*m*, Figure 301) at the surface of the water. The water in quadrants (*a*) and (*d*) attracts the molecule (*m*) and tends to pull it downward. As there is no water in (*b*) and (*c*), — but only air, which attracts the molecule (*m*) but slightly, — the resulting effect is for the molecule (*m*) to be pulled toward the center of the water, and *every other* molecule on the surface is pulled toward the center in the same way.

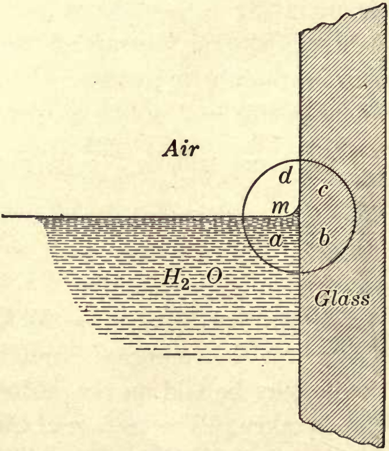

FIGURE 302. — WATER IN CONTACT WITH GLASS.

This gives the effect of a stretched covering over the surface of the liquid.

323. Capillarity. — Capillarity is an application of surface tension. Figure 302 shows water in contact with glass. The water against the glass is curved *up*; because glass has a greater attraction for water than water has for water; therefore the glass in quadrant (c) pulls the molecule of water (m) more than the water in quadrant (a). Also the glass in (b) pulls (m) more than does the air in (d). This makes the surface of the water curve as shown in the figure.

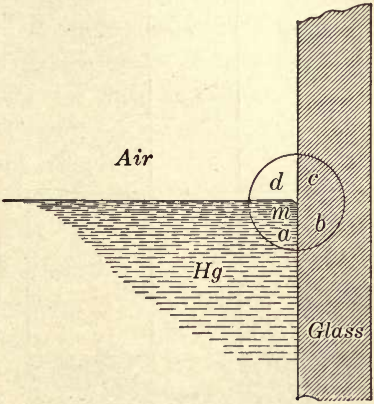

FIGURE 303. — MERCURY IN CONTACT WITH GLASS.

Figure 303 shows mercury in contact with glass. The mercury against the glass is curved *down*. Mercury attracts mercury more than glass attracts mercury, therefore the mercury in quadrant (a) pulls the molecule of mercury (m) more than the glass in quadrant (c). Also the glass in (b) attracts (m) more than the air in (d). Thus the surface curves downward as shown in the figure.

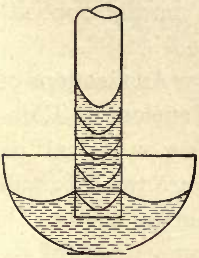

FIGURE 304. — HOW WATER CREEPS UP A GLASS TUBE.

When a tube is put into a vessel of water, the water creeps up the tube, as shown in Figure 304. When a tube is put into a vessel of mercury, the mercury creeps down the tube. (Figure 305.) This is called *capillarity.*

The steps in this process are as follows:

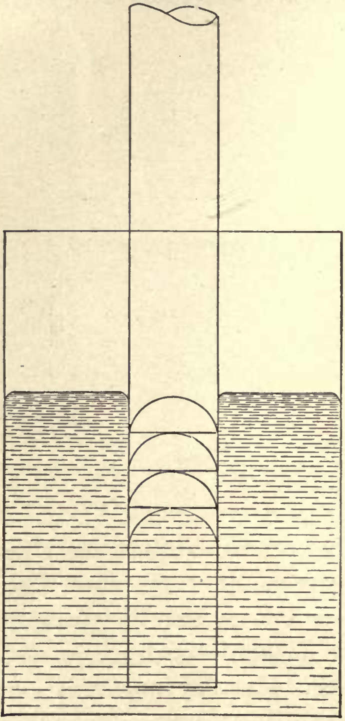

FIGURE 305.—HOW MERCURY CREEPS DOWN A GLASS TUBE.

When the tube is placed in the water (Figure 304), the surface of the water curves up the glass; but since the surface tension on the water acts like a rubber covering, the surface straightens out; and then curves again. This alternation is kept up until the weight of water in the tube is so great that the surface tension is not able to lift it and straighten out the surface.

In the case of mercury and glass the mercury is pressed down (Figure 305), the process being the same as for water, except that the surface curves in the opposite direction.

324. Other Applications of Surface Tension. — Raindrops become spherical on account of surface tension. The elastic surface tends to pull all molecules towards the center, thus producing a sphere.

Drops of water on a greased surface become spherical for the same reason. Similarly, drops of mercury on a table or your hand become spherical.

Soap-bubbles are thin films of soapy water with a double surface tension — one on the inside, and one on the outside. Sometimes you can see the water run down between the two surfaces.

The fact that the white of an egg has a high surface tension makes it possible to "beat" it into a white fluffy mass. This fluffy mass is made up of thousands of tiny bubbles which depend on surface tension for their existence.

Oil is sometimes poured on stormy seas to stop the breaking of the waves and thus save the ship. The *three* surface tensions act as a blanket over the water. Explain why there are *three* surface tensions.

325. Archimedes' Principle. — Archimedes formulated the following principle:

A body immersed in a fluid loses in weight an amount equal to the weight of the fluid displaced.

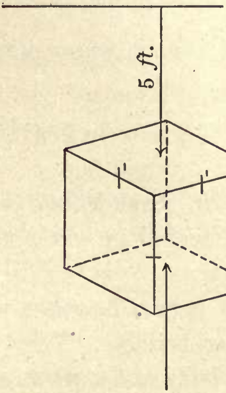

FIGURE 306. — ARCHIMEDES' PRINCIPLE VERIFIED.

This principle can be demonstrated as follows: Suppose a cube 1 ft. on an edge be immersed in water so that the top of the cube is 5 ft. below the surface. (Figure 306.) Then the bottom of the cube is 6 ft. below the surface. The force *downward* on the top of the cube equals

$$F = h \cdot D \cdot A$$
$$F = 5 \times 62\tfrac{1}{2} \times 1 = 312\tfrac{1}{2} \text{ lb.}$$

The force *upward* on the bottom of the cube equals

$$F = h \cdot D \cdot A$$
$$F = 6 \times 62\tfrac{1}{2} \times 1 = 375 \text{ lb.}$$

This leaves a force upward of $375 - 312\frac{1}{2}$ lb. $= 62\frac{1}{2}$ lb. But $62\frac{1}{2}$ lb. is the weight of a cubic foot of water, which is also the volume of the cube.

The illustration above assumed that the body was completely submerged. If the weight of the body is *less* than the weight of an equal volume of liquid, then the body will sink to a depth where it displaces a weight of liquid equal to the weight of the body.

For example, if a body of one cubic foot weighs 40 lb., it will sink in water until it displaces 40 lb. of water, or $\frac{40}{62.5}$ cu. ft.

Thus a body heavier than a liquid sinks, and one lighter than a liquid floats.

326. Applications of Archimedes' Principle. — A stone submerged in water is much easier to lift than one out of water.

A person in water weighs very little. This makes swimming possible. Why does the swimmer keep as much of his body *under* water as possible?

An egg will sink in fresh water but will float in salt water. Explain.

Grapefruit and oranges may be tested for juiciness by dropping them into water. If they are juicy and heavy, they will float very *low* in the water, but if dry and light, they will float *high*.

A ship sinks in water until the weight of the water displaced equals the weight of the ship and its cargo. That is the reason why an empty freighter rides *high* and a loaded one rides *low* in the water.

327. Density and Specific Gravity. — *The term density means the mass per unit volume.* A cubic foot of water contains $62\frac{1}{2}$ lb., and a cubic centimeter contains 1 gram. Therefore the density of water is $62\frac{1}{2}$ lb. per cubic foot, or 1 gram per cubic centimeter.

Specific gravity is the ratio of the mass of a body to the mass of an equal volume of water.

$$\textit{Specific gravity} = \frac{\textit{mass of body}}{\textit{mass of equal vol. of water}}.$$

Specific gravity is a comparison of the *density* of a body to the *density* of water.

Since the density of water in the metric system is numerically 1 (1 gram per cubic centimeter), the specific gravity and the density of a body in that system are numerically equal.

By the use of the table on the next page the weight of any certain volume of a substance can be found, or the volume of any certain weight can be found.

Example: What is the weight of 25 cu. ft. of copper?

From the table: 1 cu. ft. copper = 550.6 lb.

$$25 \text{ cu. ft.} = 25 \times 550.6 = 13765 \text{ lb.}$$

Example: What is the volume of 1000 lb. of cast iron?

From the table: 1 cu. ft. cast iron = 449 lb.

$$\frac{1000}{449} = 2.23 \text{ cu. ft.}$$

Problems

1. What is the weight of a cedar chest that is made of 2 cu. ft. of lumber?

2. If a gold chain weighs 30 grams, how many cubic centimeters of gold does it contain?

3. Why is cork used in life preservers?

4. A gallon contains 231 cu. in., and a cu. ft. contains 1728 cu. in. What is the weight of a gallon of water?

TABLE OF DENSITIES AND SPECIFIC GRAVITIES OF SOME SUBSTANCES

Substance	Density		Specific Gravity
	Lb. per Cu. Ft.	Gms. per c.c.	
Ash (dry)	43.7	.70	.70
Ash (green)	52.8	.84	.84
Acetic Acid	66.4	1.062	1.062
Alcohol	50.0	.80	.80
Aluminum	165.6	2.65	2.65
Beech	53.2	.69 to .852	.69 to .852
Cedar	35.0	.561	.561
Cork	15.0	.24	.24
Copper (cast)	550.6	8.81	8.81
Copper (sheet)	555.0	8.88	8.88
Brass	527.5	8.38 to 8.44	8.38 to 8.44
Gold	1218.8	19.50	19.50
Hydrochloric Acid	75.2	1.22	1.22
Iron (wrought)	480.0	7.68	7.68
Iron (cast)	449.0	7.20	7.20
Lead	709.6	11.36	11.36
Maple	46.0	.75	.75
Mercury	850.0	13.6	13.6
Milk	64.5	1.032	1.032
Nitric Acid	76.3	1.22	1.22
Oak	53.1	.85	.85
Pine	28.8	.46	.46
Platinum	1348.8	21.5	21.5
Sea Water	64.4	1.03	1.03
Silver	656.3	10.5	10.5
Spruce	31.2	.5	.5
Steel	590.0	7.84	7.84
Sulphuric Acid	115.1	1.84	1.84
Tin (cast)	455.8	7.29	7.29
Walnut	41.6	.67	.67
Water	62.5	1.00	1.00
Zinc	431.3	6.9	6.9

5. If there were 12 cubes of gold, 1 in., 2 in., 3 in., etc., on an edge respectively, and you were told you could have whichever one you could lift at the first trial, which one would you try? Why?

6. If a bucket containing water is placed on the platform of a set of scales and is found to weigh 40 lb., what weight will the scales show if a cast iron cube 3 in. on an edge is supported just under the surface of the water by a string, care being taken that the cube does not touch the bucket?

7. How could you find the cubical contents of an egg?

8. From the table determine the order of the heaviest substances named.

328. Methods of Finding Specific Gravity. — (1) If it is possible to weigh a body and also to determine its volume, the density can be found by *dividing the weight by the volume.* If the body can be weighed and the dimensions taken, then the weight divided by the volume gives the *density.* This density divided by the density of water gives its specific gravity.

Example: What is the specific gravity of a piece of metal if it weighs 40 lb., and is 2″ × 4″ × 12″?

Solution:

$$2 \times 4 \times 12 = 96 \text{ cu. in.}$$

$$96 \text{ cu. in.} = \frac{96}{1728} = \frac{1}{18} \text{cu. ft.}$$

$$\frac{40}{\frac{1}{18}} = 40 \times 18 = 720 \text{ lb. per cubic foot.}$$

$$\text{Density of water} = 62.5 \text{ lb. per cubic foot.}$$

$$\therefore \quad \frac{720}{62.5} = 11.5 = \text{sp. gr.}$$

(2) The *hydrometer* (Figure 307) is an instrument used to determine the specific gravity of liquids. It is a tube, weighted at the bottom, that has a scale marked on the side. The depth to which it sinks gives the specific gravity reading.

An hydrometer, made to read the specific gravities of liquids lighter than water, has the zero of the scale at the bottom, but one for liquids heavier than water has the zero at the top. Why?

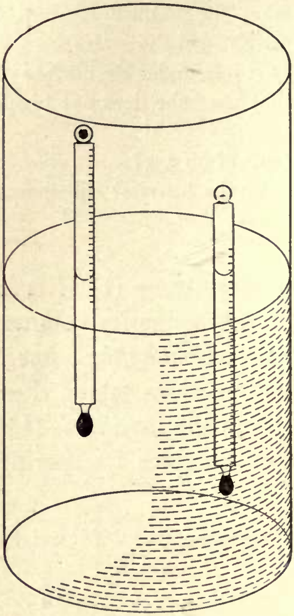

FIGURE 307. — THE HYDROMETER.

(3) Another method for finding the specific gravity of a body, and the one generally used if the body is irregular in shape, is to weigh the body in air, and then in water. The difference represents the weight of the water displaced. Why? Then the weight in air divided by the loss in weight equals specific gravity.

Example: What is the specific gravity of a body which weighs 19 grams in air and 12 grams in water?

Solution:

$19 - 12 = 7$ grams, wt. of water displaced.

$$\frac{19}{7} = 2.71 = \text{sp. gr.}$$

(4) Other cases: (*a*) If the body is lighter than water, a sinker must be used; but the principle is similar.

(*b*) If the object is soluble in water, it can be weighed in a liquid in which it is not soluble, but whose specific gravity is known.

(*c*) If it is a liquid whose specific gravity is to be found, a sinker, first weighed in air, then in water, and then in the liquid, will give the data necessary for finding the specific gravity.

Explain, with an example, how to find the specific gravity in (*a*), (*b*), and (*c*).

Problems

1. What is the density and specific gravity of a piece of butter which is $2\frac{1}{2}'' \times 2\frac{1}{2}'' \times 4''$ and weighs 1 lb.?

2. What is the specific gravity of an egg, if it weighs 1 oz. in air and .1 oz. in water?

3. What is the specific gravity of a grapefruit, if the following data are taken? Weight of grapefruit in air, with a sinker attached, but in water, equals 1.5 lb.; weight of sinker alone in water equals .3 lb.; weight of grapefruit in water with sinker attached and in water equals .1 lb.

4. What is the specific gravity of a crystal of a substance, if it weighs .24 gram in air, and .05 gram in a liquid whose specific gravity is 1.5?

5. What is the specific gravity of a liquid, if a sinker weighs 12 grams in air, 5 grams in the liquid, and 4 grams in water?

Review Problems

1. Define force, work, mechanical advantage, and efficiency.

2. Classify and describe levers.

3. If a force of 15 lb. is exerted on the handles of a nutcracker 6 inches from the pivot when the nut is placed $1\frac{1}{2}$ inches from the pivot, what is the pressure on the nut?

4. The crank on an awning lifter is 15 inches long, and the radius of the axle on which the rope is wound is 1 inch. What force on the crank is necessary to lift the awning if it pulls down on the rope with a weight of 50 lb.?

5. If a piano weighs 600 lb. and is rolled up a plank 16 ft. long into a truck 4 ft. high, what force is necessary, ignoring friction?

6. How fast will the blades of an egg-beater run, if the handle is fastened to a wheel with 50 cogs, which in turn drives a wheel, with 8 cogs, directly connected to the blades, the handle being turned 96 R. P. M.?

7. What horsepower is exerted when a 120-lb. girl climbs a stairs 15 ft. high in $\frac{1}{4}$ min.?

8. Define motion.

9. What are Newton's three laws of motion?

10. Explain the use of the parallelogram of force.

11. How far will a train travel in 10 seconds if it has an acceleration of $\frac{1}{2}$ ft. per second, per second, and starts from rest?

12. How long will it take a stone to fall 100 ft.?

13. How far will an automobile coast if it has a velocity of 36 ft. per second and slows down at the rate of 2 ft. per second, per second?

14. What is the apparent weight of a girl going up in an elevator which is increasing its speed at the rate of 3 ft. per second, per second, if her actual weight is 110 lb.?

15. Give two uses of the pendulum.

16. Explain why gases and liquids can be delivered through pipes while solids cannot.

17. How does *force* on a surface differ from *pressure* on a surface?

18. What is the pressure in pounds per square inch at the bottom of a tank of water 8 ft. deep?

19. If the water main pressure is 60 lb. per square inch, how high will the water rise in a pipe?

20. Why do high buildings have ext a pumping systems of their own?

21. If you were to supply water to a house, from an open tank, where would you locate the tank?

22. Give five applications of air-pressure.

23. Explain capillarity.

24. State Archimedes' principle.

25. What is meant when we say the specific gravity of brass is 8.3?

26. Why will an egg sink in fresh water and float in salt water?

27. How could you test a grapefruit for juiceness in a simple manner?

28. What is the specific gravity of an egg, if it weighs 1.1 oz. in air, and .08 oz. in water?

APPENDIX

I. Freezing and Boiling Points of Some Common Substances

Under Normal Atmospheric Pressure

Substance	Freezing Point	Boiling Point
	Centigrade	Centigrade
Oxygen	– 235°	– 182°
Ammonia	– 75°	– 39°
Ether	– 113°	35°
Methylic Alcohol	– 112°	66°
Distilled Water	0°	100°
Acetic Acid	– 17°	117°
Turpentine	– 27°	157°
Fat, Oil, etc.	– 33°	210°
Mercury	– 38.8°	357°

II. Vapor Tension of Water

Temperatures Given in Centigrade Degrees, and Vapor Tension in Centimeters of Mercury

Temperatures	Vapor Tensions	Temperatures	Vapor Tensions
– 10	.22	3	.57
– 9	.23	4	.61
– 8	.25	5	.65
– 7	.27	6	.70
– 6	.29	7	.75
– 5	.32	8	.80
– 4	.34	9	.86
– 3	.37	10	.92
– 2	.39	11	.98
– 1	.42	12	1.05
0	.46	13	1.12
1	.49	14	1.19
2	.53	15	1.27

II. Vapor Tension of Water — *Continued*

TEMPERATURES	VAPOR TENSIONS	TEMPERATURES	VAPOR TENSIONS
16	1.35	30	3.15
17	1.44	31	3.34
18	1.54	32	3.54
19	1.63	33	3.74
20	1.74	34	3.96
21	1.85	35	4.18
22	1.97	36	4.42
23	2.09	37	4.67
24	2.22	38	4.93
25	2.35	39	5.20
26	2.51	40	5.49
27	2.65	41	5.79
28	2.81	45	7.14
29	2.98	100	76.00

III. Table of Specific Heats of Some of Our Most Common Substances

SUBSTANCE	SPECIFIC HEAT
Aluminum	.22
Brass	.094
Copper	.095
Iron	.1138
Mercury	.038
Lead	.031
Ice	.5
Air (at constant pressure)	.2375
Hydrogen (at constant pressure)	3.4
Steam (at constant pressure)	.48

IV. Table of Coefficients of Linear Expansion

SUBSTANCES	COEFFICIENT	SUBSTANCES	COEFFICIENT
Aluminum	.0000222	Iron	.0000112
Brass	.0000187	Platinum	.0000088
Copper	.000017	Steel	.000013 (tempered)
Glass	.0000083	Steel	.000011 (untempered)

If the range in temperature is given in Fahrenheit degrees, then the above coefficients must be multiplied by $\frac{5}{9}$.

V. Sources of Heat

MATERIAL	KIND	HEAT VALUE
Coal	Hard	14000 B. T. U.'s per lb.
	Soft	12000 B. T. U.'s per lb.
	Coke	14000 B. T. U.'s per lb.
Wood	Hard	8400 B. T. U.'s per lb.
	Soft	8600 B. T. U.'s per lb.
Gas	Natural	1200 B. T. U.'s per cu. ft.
	Artificial	600 B. T. U.'s per cu. ft.
Oils	Kerosene	20000 B. T. U.'s per lb.
	Naphtha	20000 B. T. U.'s per lb.
	Crude Oil	18000 B. T. U.'s per lb
Electricity		3411.72 B. T. U.'s per kw. hr.

(Electricity is given in this table, though it is not a fuel.)

VI. Heat Value of Foods

FOOD (edible portion)	APPROXIMATE MEASURE OF 100-GREAT-CALORY PORTION	WEIGHT IN OUNCES OF 100-GREAT-CALORY PORTION
Almonds	15 average	0.5
Apples	2 medium	6.5
Apricots, fresh	2 large	6.1
Asparagus, cooked	2 servings	7.5
Bacon, smoked (uncooked)	1 thin slice, small	0.6
Bananas	1 large	3.6
Beans, baked, canned	1 small serving (½ cupful)	2.8
string, canned	5 servings	17.2
lima, canned	1 large side-dish	4.6
Beef, corned	. . . .	1.2
dried, salted and smoked	4 large slices	2.0
porterhouse steak	1 small	1.3
ribs, lean	1 average serving	1.9
ribs, fat	. . . .	0.9
round, free from visible fat	1 generous serving	3.1
rump, lean	. . . .	1.7
rump, fat	. . . .	0.9
sirloin steak	1 average serving	1.4

VI. Heat Value of Foods — *Continued*

Food (edible portion)	Approximate Measure of 100-Great-Calory Portion	Weight in Ounces of 100-Great-Calory Portion
Beets, cooked	3 servings	8.9
Brazil nuts	3 average size	0.5
Bread, graham	1 thick slice	1.3
toasted	2 medium slices (baker's)	1.2
white homemade	1 medium slice	1.3
average	1 thick slice	1.3
whole-wheat	1 thick slice	1.4
Buckwheat flour	¼ cupful	1.0
Butter	1 tablespoonful (ordinary pat)	0.5
Buttermilk	1¼ cupfuls (1½ glasses)	9.9
Cabbage	2 servings	11.2
Calf's foot jelly	. . . .	4.1
Carrots, fresh	2 medium	7.8
Cauliflower	. . . .	11.6
Celery	. . . .	19.1
Celery soup, canned	2 servings	6.6
Cheese, American pale	1½ cubic inches	0.8
American red	1½ cubic inches	0.8
Cheddar	1½ cubic inches	0.8
Cottage	4 cubic inches (½ cupful)	3.2
Neufchatel	1½ cubic inches (¼ cupful)	1.1
Roquefort	1½ cubic inches	1.0
Swiss	1½ cubic inches	0.8
Chicken, broilers	1 large serving	3.3
Chocolate	1 generous half square	0.6
Cocoa	2½ tablespoonfuls	1.0
Cod, salt	. . . .	3.4
Corn, green	1 side-dish	3.6
Corn meal	2 tablespoonfuls	1.0
Crackers, graham	3 crackers	0.9
soda	3 crackers	0.9
water	3 crackers	0.9
Cranberries, cooked	½ cupful	7.5
Cream	¼ cupful	1.8
Cucumbers	2 large	20.3
Dates, dried	4 medium	1.0
Doughnuts	½ doughnut	0.8

VI. Heat Value of Foods—*Continued*

FOOD (edible portion)	APPROXIMATE MEASURE OF 100-GREAT-CALORY PORTION	WEIGHT IN OUNCES OF 100-GREAT-CALORY PORTION
Eggs, uncooked	1½ medium or 2 small	2.4
Farina		1.0
Figs, dried	1 large	1.1
Flour, rye	¼ cupful	1.0
wheat, entire	¼ cupful	1.0
wheat, graham	¼ cupful	1.0
wheat, average high, medium	¼ cupful	1.0
Gelatin	4 tablespoonfuls	1.0
Grapes	1 large bunch	3.7
Haddock		4.9
Halibut steaks	1 average serving	2.9
Ham, fresh, lean		1.5
fresh, medium	1 average serving	1.1
smoked, lean		1.3
Herring, whole		2.5
Hominy, uncooked	¼ cupful	1.0
Lamb, chops, broiled	1 small chop	1.0
leg, roast	1 average serving	1.8
Lard, refined	1 tablespoonful (scant)	0.4
Lemons	3 medium	8.0
Lettuce	50 large leaves	20.4
Liver, veal, uncooked	2 small servings	2.9
Macaroni, uncooked	¼ cupful (4 sticks)	1.0
Macaroons	2	0.8
Mackerel, uncooked	1 large serving	2.5
salt		1.2
Marmalade, orange	1 tablespoonful	1.0
Milk, condensed, sweetened	$1\frac{1}{16}$ cupfuls	1.1
skimmed	1¼ cupfuls	9.6
whole	⅝ cupful (half glass)	5.1
Molasses, cane	⅛ cupful	1.2
Muskmelons	½ large serving	8.9
Mutton, leg	1 average serving	1.8
Oatmeal, uncooked	⅛ cupful	0.9
Olives, green	7 to 10	1.2
Onions, fresh	2 medium	7.3
Oranges	1 very large	6.9

VI. Heat Value of Foods—*Continued*

Food (edible portion)	Approximate Measure of 100-Great-Calory Portion	Weight in Ounces of 100-Great-Calory Portion
Oysters, canned	5 oysters	4.9
Parsnips	1 large	5.4
Pea soup, canned	1 large serving	3.5
Peaches, canned	1 large	7.5
fresh	4 medium	8.5
Peanuts	10 to 12 (double kernels)	0.6
Peas, dried, uncooked	2 tablespoonfuls	1.6
canned	2 servings	6.3
green	1 generous serving	3.5
Pies, apple	⅓ piece	1.3
custard	⅓ piece	2.0
lemon	⅓ piece	1.4
mince	¼ piece	1.2
squash	⅓ piece	2.0
Pineapples, fresh	5 slices	8.2
canned	1 small serving	2.3
Pork, chops, medium	1 very small serving	1.1
fat, salt	. . . .	0.5
Potatoes, white, uncooked	1 medium	4.2
sweet, uncooked	½ medium	2.9
Prunes, dried	3 large	1.2
Raisins	⅛ cupful (packed solid)	1.0
Rhubarb, uncooked	3½ cupfuls (scant)	15.3
Rice, uncooked	2 tablespoonfuls	1.0
Salmon, whole	1 small serving	1.7
Shad, whole	1 average serving	2.2
Shredded wheat	1 biscuit	1.0
Spinach, fresh	3 ordinary servings (cooked)	14.7
Succotash, canned	1 average serving	3.6
Sugar	3 lumps, 5 teaspoonfuls granulated, 6½ teaspoonfuls powdered	0.9
Tomatoes, fresh	4 average servings	15.5
canned	1¾ cupfuls	15.6
Turkey	1 serving	1.2
Turnips	2 large servings (2 turnips)	9.0
Veal, cutlet	. . . .	2.3

VI. Heat Value of Foods—*Continued*

FOOD (edible portion)	APPROXIMATE MEASURE OF 100-GREAT-CALORY PORTION	WEIGHT IN OUNCES OF 100-GREAT-CALORY PORTION
fore quarter	1 thick slice	2.3
hind quarter	. . . .	2.3
Vegetable soup, canned . .	. . . .	25.9
Walnuts, California . . .	. . . .	0.5
Wheat, cracked	4 nuts	1.0
Whitefish	. . . .	2.4
Zwiebach	. . . .	0.8

VII. Tables of Measurements

English Lineal Measure

12 inches = 1 foot
3 feet = 1 yard
5½ yards = 1 rod
320 rods = 1 mile

Lineal Chain Measure

7.92 inches = 1 link
100 links = 1 chain
80 chains = 1 mile

Rope and Cable Measure

6 feet = 1 fathom
120 fathoms = 1 cable's length

Cloth Measure

2.25 inches = 1 nail
4 nails = 1 quarter
5 quarters = 1 ell

Metric Lineal Measure

10 millimeters = 1 centimeter
10 centimeters = 1 decimeter
10 decimeters = 1 meter
10 meters = 1 dekameter
10 dekameters = 1 hektameter
10 hektameters = 1 kilometer
10 kilometers = 1 myriameter

Equivalent values in English and Metric Lineal Measure

1 inch = 2.54 centimeters
1 foot = 30.48 centimeters
1 yard = 91.44 centimeters
1 rod = 502.92 centimeters
1 mile = 160,934.72 centimeters
1 centimeter = .394 inch

English Surface Measure

144 square inches = 1 square foot
9 square feet = 1 square yard
30¼ square yards = 1 square rod
160 square rods = 1 acre
640 acres = 1 square mile

Architect's Measure

1 square = 100 square feet

Metric Surface Measure

100 square millimeters = 1 square centimeter
100 square centimeters = 1 square decimeter
100 square decimeters = 1 square meter
100 square meters = 1 square dekameter
100 square dekameters = 1 square hektameter
100 square hektameters = 1 square kilometer
100 square kilometers = 1 square myriameter

Equivalent values in English and Metric Measure

1 square inch = 6.45 square centimeters
1 square foot = 929.03 square centimeters
1 square yard = 8361.29 square centimeters
1 square rod = 252,929.04 square centimeters
1 square centimeter = .155 square inch

English Measure Volume

1728 cubic inches = 1 cubic foot
27 cubic feet = 1 cubic yard

A standard gallon contains 231 cubic inches, and a standard *struck* bushel contains 2150.42 cubic inches.

English Liquid Measure

4 gills = 1 pint
2 pints = 1 quart
4 quarts = 1 gallon

English Dry Measure

2 pints = 1 quart
4 quarts = 1 gallon
2 gallons = 1 peck
4 pecks = 1 bushel

English Fluid Measure

8 drams = 1 ounce
16 ounces = 1 pint
2 pints = 1 quart
4 quarts = 1 gallon

Metric Measure of Volume

1000 cubic millimeters = 1 cubic centimeter
1000 cubic centimeters = 1 cubic decimeter
1000 cubic decimeters = 1 cubic meter
1000 cubic meters = 1 cubic dekameter
1000 cubic dekameters = 1 cubic hektameter
1000 cubic hektameters = 1 cubic kilometer
1000 cubic kilometers = 1 cubic myriameter

Metric Liquid and Dry Measure

10 milliliters = 1 centiliter
10 centiliters = 1 deciliter
10 deciliters = 1 liter
10 liters = 1 dekaliter
10 dekaliters = 1 hektaliter
10 hektaliters = 1 kiloliter
10 kiloliters = 1 myrialiter

The liter contains 1 cubic decimeter or 1000 cubic centimeters.

Equivalent values in English and Metric Volume Measure

1 cubic centimeter = .061 cubic inch
1 cubic meter = 1.308 cubic yards
1 liter = .908 dry quart = 1.057 liquid quarts

English Measures of Weight

16 ounces = 1 pound
2000 pounds = 1 ton

Metric Measures of Weight

10 milligrams = 1 centigram
10 centigrams = 1 decigram
10 decigrams = 1 gram
10 grams = 1 dekagram
10 dekagrams = 1 hektogram
10 hektograms = 1 kilogram
10 kilograms = 1 myriagram

Equivalent values in English and Metric Measures of Weight

453.6 grams = 1 pound

VIII. Vibrations of Musical Sounds

Letter	C	D	E	F	G	A	B	C_2
Frequency	256	288	320	$341\frac{1}{4}$	384	$426\frac{2}{3}$	480	512
Interval between consecutive tones		$\frac{9}{8}$	$\frac{10}{9}$	$\frac{16}{15}$	$\frac{9}{8}$	$\frac{10}{9}$	$\frac{9}{8}$	$\frac{16}{15}$
Interval between each tone and C	1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2

IX. Candle-Power of a Few Sources of Light

Carbon Lamp	about $\frac{2}{7}$ c. p. per watt
Tungsten Lamp	about $\frac{4}{5}$ c. p. per watt
Nitrogen Lamp	about 1 c. p. per watt
Mercury Vapor Lamp	about 1 c. p. per watt
Arc Light	about 1 c. p. per watt

X. Terms and Abbreviations in Electricity

THING TO BE MEASURED	UNIT	LETTER
Pressure	Volt	E
Current	Ampere	I
Resistance	Ohm	R
Power	Watt	W
	Kilowatt	Kw
Electrical Energy	Watt-hour	W-hr.
	Kilowatt-hour	Kw-hr.

XI. Table of Densities and Specific Gravities of Some Substances

SUBSTANCE	DENSITY		SPECIFIC GRAVITY
	Lbs. Per Cu. Ft.	Gms. Per c. c.	
Ash (dry)	43.7	.70	.70
Ash (green)	52.8	.84	.84
Acetic Acid	66.4	1.062	1.062
Alcohol	50.0	.80	.80
Aluminum	165.6	2.65	2.65
Beech	53.2	.69 to .852	.69 to .852
Cedar	35.0	.561	.561
Cork	15.0	.24	.24
Copper (cast)	550.6	8.81	8.81
Copper (sheet)	555.0	8.88	8.88
Brass	527.5	8.38 to 8.44	8.38 to 8.44
Gold	1218.8	19.50	19.50
Hydrochloric Acid	75.2	1.22	1.22
Iron (wrought)	480.0	7.68	7.68
Iron (cast)	449.0	7.20	7.20
Lead	709.6	11.36	11.36
Maple	46.0	.75	.75
Mercury	850.0	13.6	13.6
Milk	64.5	1.032	1.032
Nitric Acid	76.3	1.22	1.22
Oak	53.1	.85	.85
Pine	28.8	.46	.46
Platinum	1348.8	21.5	21.5
Sea Water	64.4	1.03	1.03
Silver	656.3	10.5	10.5
Spruce	31.2	.5	.5
Steel	590.0	7.84	7.84
Sulphuric Acid	115.1	1.84	1.84
Tin (cast)	455.8	7.29	7.29
Walnut	41.6	.67	.67
Water	62.5	1.00	1.00
Zinc	431.3	6.9	6.9

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